Towards a Secure and Renewable Hydrogen Economy for Asia:

Fundamentals
International Experience and
Steps Forward

Anchor Document
Renewable Hydrogen Conference
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List of Acronyms

ACE	ASEAN Center for Energy
AER	Alternative Energy Requirement (Ireland)
AEZ	AgroEcological Zones
AFC	Alkaline Fuel Cell
APU	Alternative Power Unit
ASEAN	Association of Southeast Asian Nations
ASES	American Solar Energy Society
BTU	British Thermal Unit
CCT	Clean Coal Technology
Chl	Chlorophyll
CO	Carbon Monoxide
CO2	Carbon Dioxide
CSIRO	Commonwealth Scientific and Industrial Research Organization (Australia)
CSP	Concentrating Solar Power
DMFC	Direct Methanol Fuel Cell
EC	European Commission
ECTOS	Ecological City Transport System
EERE	Energy Efficiency and Renewable Energy (USDOE unit)
EPIRA	Electric Power Industry Reform Act (Philippines)
EU	European Union
FCHV	Fuel Cell Hybrid Vehicle
FCV	Fuel Cell Vehicle
GHG	Greenhouse Gas
GIS	Geographic Information System
GJ	Gigajoules
GPS	Geospatial Positioning System
GTR	Global Technical Regulation
H2	Hydrogen
H2FCC	Hydrogen and Fuel Cell Committee (Canada)
H2O	Water
HIA	Hydrogen Implementing Agreement (of IEA)
HVDC	High Voltage Direct Current
ICE	Internal Combustion Engine
IEA	International Energy Agency
IEC	International Electrotechnical Commission
IPHE	International Partnership for the Hydrogen Economy
ISO	International Organization for Standardization
JHFC	Japan Hydrogen and Fuel Cells
KHK	The High-Pressure Gas Safety Institute of Japan
LCA	Life Cycle Analysis
LHV	Lower Heating Value
LiAlO2	Lithium Aluminum Oxide
MCFC	Molton Carbonate Fuel Cell
NASA	National Aeronautics and Space Administration (U.S.)
NFFO	Non Fossil Fuel Obligation (United Kingdom)
NGV	Natural Gas Vehicle
NREL	National Renewable Energy Laboratory (of USDOE)
NWTC	National Wind Technology Center (NREL)
O2	Oxygen

PAFC	Phosphoric Acid Fuel Cell
PEM	Proton Exchange Membrane or Polymer Electrolyte Membrane
PEMFC	Proton Exchange Membrane Fuel Cell
psi	pounds per square inch
PV	Photovoltaic
R&D	Research and Development
REC	Renewable Energy Certificate
RP2	Renewable Energy “Power Packs”
RPS	Renewable Portfolio Standard
SARI/E	South Asia Regional Initiative/Energy Program
Si	Silicon
SMR	Steam Methane Reforming
SWNT	Single-Wall Nanotubes
TUV	German Technical
UKM	Universiti Kebangsaan Malaysia
UTM	Universiti Teknologi Malaysia
U.N.	United Nations
U.S.	United States
USA	United States of America
USAID	U.S. Agency for International Development
USDOE	U.S. Department of Energy
WEC	World Energy Council

Executive Summary

Renewable hydrogen can enhance energy security throughout the world and strengthen foundations for global peace and prosperity. This report provides background information on renewable hydrogen pathways, focusing on broad benefits, opportunities, and options for creating renewable hydrogen in locations worldwide.

The report is the anchor document for the USAID-supported Renewable Hydrogen Workshop being held as part of the Philippine Energy Week Celebration, December 7-9, 2004, in Manila.

The three major themes of the workshop and this document are:

- Renewable hydrogen economy fundamentals;
- International renewable hydrogen experience; and
- Towards a secure and renewable hydrogen future for Asia—possible paths forward.

The goals of the workshop are to:

- Introduce the fundamentals of a renewable hydrogen economy;
- Provide information on hydrogen-related activities around the world;
- Illustrate the excellent renewable energy resources in Asia;
- Identify strategies to achieve greater energy security through renewable hydrogen; and
- Initiate actions to make this vision a reality throughout Asia and other parts of the world.

The anchor document supports the first three goals. The last goal will be reached through detailed country- and region-specific presentations and discussions at the workshop. **The workshop findings on strategies and next steps will be synthesized in a follow-up report to the anchor document presented here.**

The renewable hydrogen vision is for all regions of the world, including those that currently rely on non-renewable energy, to be part of a renewable hydrogen framework -- made possible by technological, economic and political advances -- that enables energy security, worldwide environmental quality, and social equity. This vision is attainable.

Renewable hydrogen can be derived from a diverse array of resources, conversion technologies, and distribution options. The marriage between hydrogen and solar/wind brings secure, clean energy—as well as making PV/wind a "24-hour power" option. In some locations, geothermal and hydro-based renewable hydrogen are already in operation.

Wind energy is among the fastest-growing energy resources around the world, and has become cost-competitive with most conventional energy resources. This technology is highly suitable for use in hydrogen energy production in the many locations around the word where wind resources are adequate. Concentrating solar power (CSP) is well-positioned for greater use, since it is a proven technology, relies on a resource that is abundant in many countries; and it has firm capacity, reliability and dispatchability, especially when coupled with hydrogen technologies. Biomass is already the world's fourth foremost fuel; it is a dispatchable resource and has a reasonable amount of capacity worldwide. The thermochemical path has the potential to achieve very high solar energy-to-chemical energy conversion efficiencies. Innovative technologies like use of algae, 3rd generation PV, direct splitting of water, and biological photovoltaics, also are promising.

Much progress is being made in the development of hydrogen storage materials, which are essential for maximizing the usability of hydrogen in a wide variety of applications. Advances in fuel cells also are accelerating the versatility of hydrogen applications. Progress on the development of hydrogen-powered vehicles continues to improve the viability of hydrogen transportation.

Development of international codes and standards are underway to help ensure highest quality and safety of hydrogen-based products and services worldwide. Education programs also are helping raise public awareness of the multiple benefits of renewable hydrogen to the global society and the environment.

Economic viability of renewable hydrogen is greatly enhanced when the environmental and societal benefits of using renewable energy are taken into account. Recognition of these benefits needs to be translated into how energy is formally valued in individual countries and internationally. In some areas renewable wind, geothermal, and hydro electricity-based electrolysis pathways are already competitive with fossil fuel pathways. This is the case in Iceland's energy market where domestic renewable resources are cheaper alternatives to producing hydrogen than fossil fuels are.

Policies that provide economic incentives for renewable hydrogen in a variety of ways are enhancing progress.. Those policies that direct public funds and encourage private investors to direct their funds toward development of renewable hydrogen, public education programs, and renewable hydrogen research, development, and deployment programs also are helping to realize renewable hydrogen futures. International collaborations through multiple programs and forums are providing opportunities for accelerating this progress.

As illustrated by the international experience examples, key ingredients for attaining success in the renewable hydrogen economy are a combination of:

- Good renewable energy resources, of one kind or another, that allow a country to achieve total energy independence and energy security

- Use of these resources in developing enough economically-viable electricity and hydrogen

- Recognition of the multiple environmental and societal benefits of using renewable energy

- Support of national policies that help make the economics more favorable to renewable hydrogen

- A well-informed public that not only encourages government to support renewable hydrogen but also guarantees use of renewable hydrogen products and services

- International cooperation on renewable hydrogen research, development and deployment that encourages local development as well as advances in other countries

The ingredients for joining a renewable hydrogen economy include, first and foremost, the availability of renewable resources. Resource assessment quantifies information on resources, and helps accelerate development and deployment of technologies. Asia has a wealth of renewable energy resources, and many areas have more than one excellent resource. This means that Asia has a very promising renewable hydrogen future. Excellent renewable energy resources are very important assets since Asia has the highest projected energy demand, and among the lowest supply of fossil fuel reserves in the world.

Geothermal resources are particularly accessible in the Himalayan Geothermal Belt , Japan, Eastern China, the Philippines, Indonesia, and New Zealand. Hydropower resources are particularly high in several countries of mainland Southeast Asia (Thailand, Cambodia, Laos, Myanmar, and Vietnam) and the countries of insular Southeast Asia—Indonesia, Malaysia and Philippines), as well as in India, Nepal and Bhutan. Biomass potential is particularly high in many parts of the Asian regions where many biomass resources are readily available for multiple purposes.

Solar and wind resources are ubiquitous throughout the world. Areas with some of the highest solar resources are located in Asian countries. More detailed resource assessment identifies areas with particularly viable resources, as a function of season of the year and other factors that determine the usability of the resources. For both resources, access to infrastructure, such as road and transmission lines, influences the level of resource that is easiest to capture and the use that is more economical.

The integration of the renewable energy resource data with other key geographic datasets, within a GIS framework provides a comprehensive analytical platform to evaluate renewable energy development opportunities. The integrated resource assessment process incorporates the resource data with additional geographic datasets. These datasets include road location and condition, load centers, transmission lines, specific land use, designated protected areas, and population and settlement information.

Throughout the workshop, and particularly during day three, participants will be discussing key ingredients of renewable hydrogen development in their countries and exploring next steps. The best next steps will partially depend on the extent to which resources and other important factors are already known; and policies and plans are already in place for developing them, with the intent to move forward towards a renewable hydrogen economy.

The results of these discussions will be synthesized into post-workshop documents to help facilitate progress towards a renewable hydrogen future in individual locations, countries, and sub-regions throughout the Asia / Pacific region.

Introduction

Renewable hydrogen can enhance energy security throughout the world and, in doing so, strengthen foundations for global peace and prosperity for all. This report provides background information on renewable hydrogen pathways, focusing on broad benefits, opportunities and options for creating renewable hydrogen in locations worldwide.

The report format follows the agenda for the USAID-supported Renewable Hydrogen Workshop being held as part of the Philippine Energy Week Celebration, December 7-9, 2004 in Manila.

The three major themes are:

- Renewable hydrogen economy fundamentals;
- International renewable hydrogen experience; and
- Towards a secure and renewable hydrogen future for Asia—Possible paths forward.

The first theme, renewable hydrogen economy fundamentals:

- Introduces renewable hydrogen and energy security linkages and the architecture of renewable energy systems;
- Provides an overview of 25 years of progress through the International Energy Agency (IEA) Hydrogen Implementing Agreements (HIA) and introduces the International Partnership for the Hydrogen Economy (IPHE);
- Gives a tutorial on all aspects of the renewable hydrogen economy from production to delivery and storage to conversion to end uses and discusses safety, standards, codes and regulations as well as education and outreach; and
- Summarizes the overarching hydrogen systems economics, renewable energy policy levers and energy security and renewable hydrogen futures implementation that is grounded in thinking globally and acting locally.

The second theme, international renewable hydrogen experience,

- Presents examples from around the world (i.e., Europe, North and South America, North Asia, South Pacific, South Asia and Southeast Asia) to illustrate pathways to a hydrogen future.

The third theme, towards a secure and renewable hydrogen future for Asia—possible pathways forward:

- Discusses resource assessments and the excellent renewable energy resources available throughout Asia; and
- Provides guidelines for workshop discussions on stirring the key ingredients for joining a renewable hydrogen economy.

The goals of the workshop are to:

- Introduce the renewable hydrogen economy fundamentals;
- Provide information on activities going on around the world;
- Illustrate the excellent renewable resources in Asia;
- Identify strategies to achieve greater energy security through renewable hydrogen; and
- Initiate action to make this vision a reality throughout Asia and other parts of the world.

The anchor document supports the first three goals. The last goals will be reached through detailed country and region specific presentations and discussions at the workshop. **The workshop findings on strategies and next steps will be synthesized in a follow-up to the anchor document presented here.**

Renewable Hydrogen Economy Fundamentals

Enhancing Energy Security Through Renewable Hydrogen

A Renewable Hydrogen Energy Vision

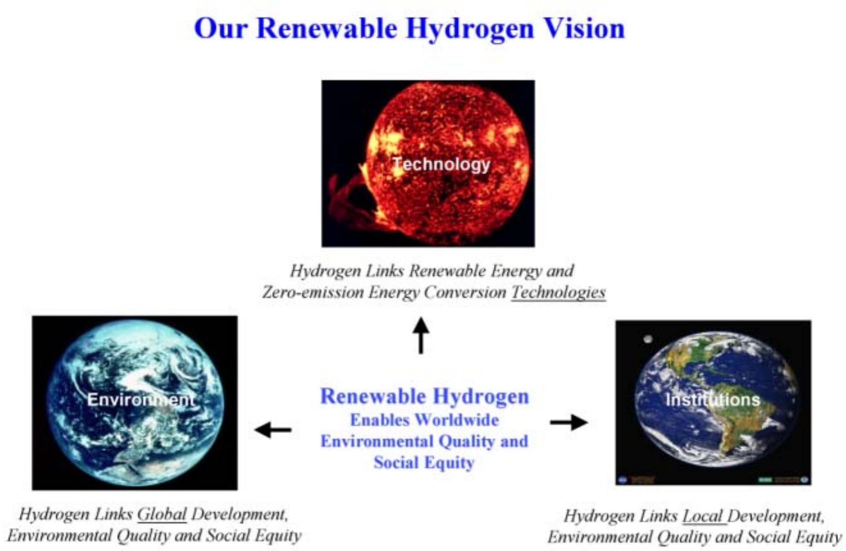
Hydrogen serves as an energy transport and storage medium. It is not an energy source itself. It is created from energy sources like solar and wind (renewable energy sources) or coal, oil, gas or nuclear (non-renewable energy sources). Renewable hydrogen is hydrogen produced from renewable energy sources. It is the renewable hydrogen that offers the promise of worldwide energy security.

Locally available renewable energy sources are used to produce electricity and other energy services. They also can be used to produce the hydrogen. The hydrogen enhances the usefulness of the renewable energy by serving as a storage and transportation medium. Hydrogen provides the important link between renewable energy and non-polluting (i.e., zero-emission) technologies like fuel cells.

Use of the locally available energy greatly reduces the multiple economic and social stresses of importing fossil fuels. This is a very important consideration, especially for Asian countries, where energy demands are projected to dramatically increase over the next couple of decades and local country oil resources are far from adequate to meet the projected demands. This means that increases in oil imports would be necessary as long as oil continues as a dominant energy source.

Renewable energy use leads to healthier environments and economies, which also in turn reinforces energy security. Using renewable energy does not result in air pollutants that lead to adverse impacts locally, regionally and around the world. Local economics also are improved since jobs needed in the renewable energy / hydrogen system are kept nearby. In addition, use of renewable energy fosters equitable access to energy services. The end result is a healthier global economy and environment.

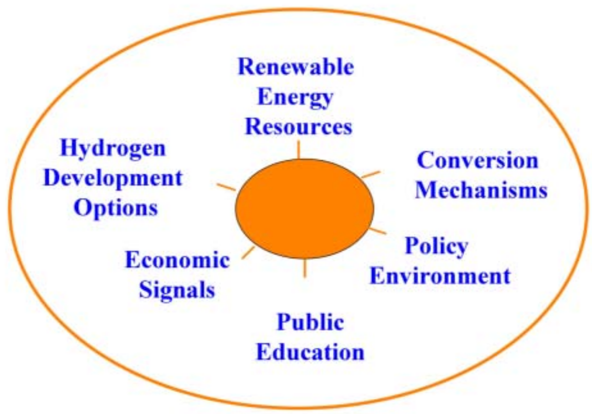
The vision is that eventually all regions of the world, including those that currently rely on non-renewable energy, will be part of the renewable hydrogen framework -- made possible by technological, economic and political advances -- that enables energy security, worldwide environmental quality and social equity.



Key Elements of Pathways to Renewable Hydrogen

The following are important steps along the pathways to the renewable hydrogen future:

- Assess and map renewable energy resources;
- Evaluate and improve mechanisms for converting renewable resources into useful energy;
- Identify and assess feasible hydrogen energy development options for all major end use sectors;
- Create appropriate outreach and education for all stakeholders; and
- Establish appropriate economic signals and favorable policy environments.



Key Elements of the Renewable Hydrogen Pathways

All of these elements are essential to the development of viable pathways to a renewable hydrogen future. The best blend of particular renewable energy resources, hydrogen development options, distribution mechanisms, economic signals, policies and education strategies will vary from country to country and region to region.

Building on Local and Regional Resources

The renewable hydrogen vision can become a global reality through building on local and regional resources. Renewable resources are abundant almost everywhere, as all energy sources are derived [ultimately] from the sun. For example, sun drives the wind and enables biomass to grow. The renewable resources in South East Asia are particularly diverse and abundant.

Benefiting from On-Going Efforts

Many countries already have strategies to achieve the renewable hydrogen vision, as exemplified by the International Energy Agency; the International Partnership for the Hydrogen Economy; and regional and national case studies from Europe, North and South America, and Asia. These efforts provide valuable lessons learned for other regions that are beginning to develop their own renewable hydrogen pathways.

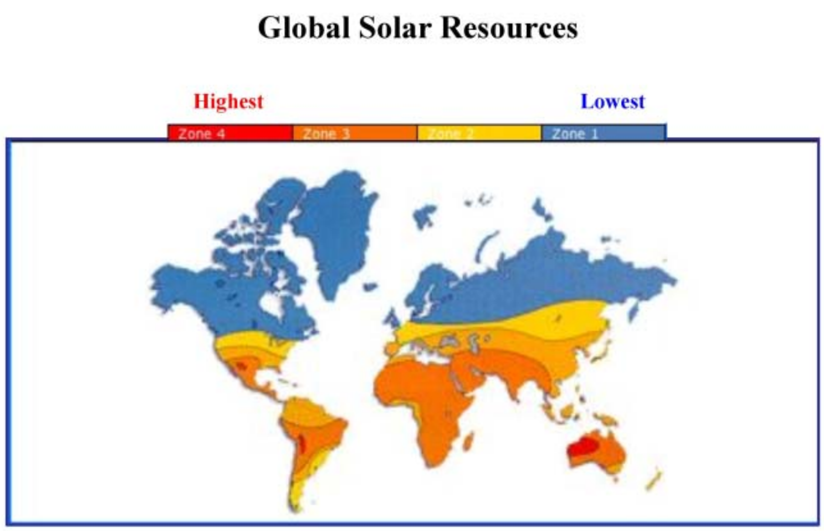
Architecture of Renewable Energy Systems

Renewable energy systems refer to the elements and their interconnections that enable renewable energy to meet the energy needs of a community, region or country. The elements include:

- Assess and map renewable energy resources;
- Evaluate and improve mechanisms for converting renewable energy into useful energy;
- Identify and assess feasible hydrogen energy development options for all major end use sectors;
- Create appropriate outreach and education for all stakeholders; and
- Establish appropriate economic signals and favorable policy environments.

Renewable Energy Resources Worldwide

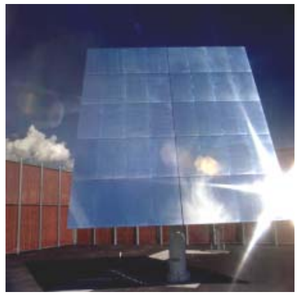
Renewable energy resource analyses are showing that there are renewable energy resources everywhere in the world and many areas have multiple renewable resources available. The entire world's energy needs can be met with renewable energy, and much can be achieved locally. This availability and diversity brings energy security to individuals and countries around the world. As illustrated below, Asia has excellent solar resources as represented by the annual average horizontal solar radiation. Red to orange colors indicate locations of the highest solar resource. This part of the world is rich in other renewable energy resources as well.



Estimated Monthly Kilo watt-hours (kWh)
Produced by Grid-Tie System at
Roof Tilt on a 2400 Watts system
Source: http://www.oksolar.com/technical/daiy_solar_radiation.html

Conversion of Renewable Energy to Useful Energy

Renewable energy resources are converted to useful energy through direct use of the energy as it is converted to electricity. In the case of solar energy, solar panels and other collection devices, as illustrated below, are used to capture the incoming solar energy and convert the energy into useable electricity. Wind energy is mechanically captured by wind turbines and converted into useable electricity. Other physical and chemical capture processes are used to harness energy from biomass, geothermal, and hydro renewable resources.



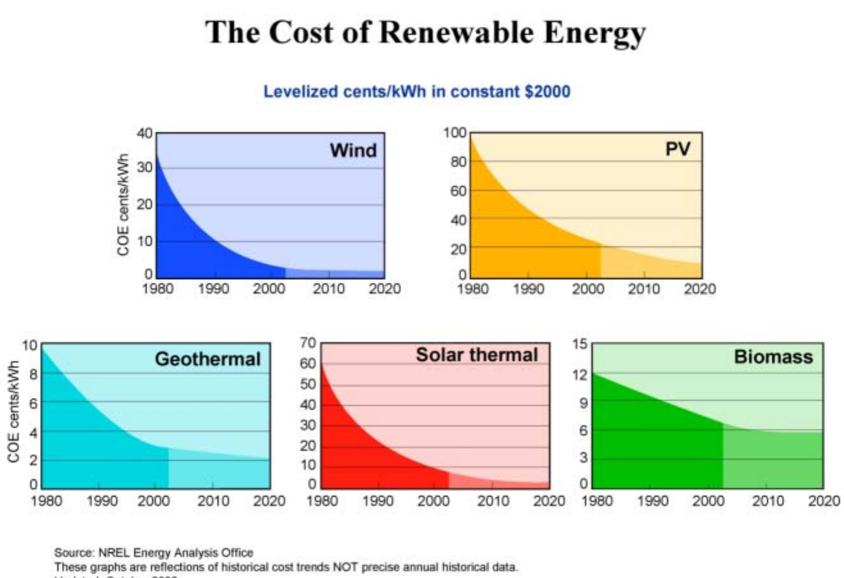
Wind **Solar Thermal** **Photovoltaics**

Examples of Zero-Emission Energy Conversion Technologies

These conversion technologies are zero-emission energy conversion technologies. The physical and chemical processes do not result in harmful pollutants as by-products of the conversion processes.

In contrast, the generation of energy from fossil fuels (i.e., coal, oil and gas) requires combustion of the fuels. The combustion leads to harmful chemical by-products such as carbon dioxide (a key greenhouse gas implicated in global climate change) and air pollutants (i.e., sulfur and nitrogen oxides, volatile organic compounds, mercury and other toxic chemicals, and fine particles) that have multiple harmful effects on human and environmental health.

These zero-emission energy conversion technologies are becoming economically competitive with fossil fuel based technologies, even without taking into account the huge environmental and social benefits and the cost savings associated with clean, renewable energy-based systems. As is illustrated below, over the past 20 years, significant cost reductions have been made in renewable electricity generation technologies. Further cost reductions are projected for the next 20 years. By using these same technologies to produce hydrogen, these economic savings become a major advantage for the renewable hydrogen production pathways (Mann, Renewable Hydrogen Forum Report, http://ases.org/)



Energy Currencies, Services and Values

Energy “currencies” are secondary or derived energy forms that can be conveniently stored, distributed, and used to provide services. The most valued of these currencies (or energy carriers) today are electricity and gasoline. In the near future, hydrogen will also become a valued energy currency, especially as a storage medium for electricity and as a fuel for fuel cells. Electricity from any energy source can be used to produce hydrogen, which can be used as a fuel or to store the electricity. Electricity and hydrogen are particularly valuable energy currencies because they are interchangeable. Indeed, Professor David Sanborn Scott of the University of Victoria in Canada refers to them as “hydricity,” or energy currency “twins” that are “mutually intra-changeable.” (International Journal of Hydrogen Energy, 29 (April 2004), 449-452)

The services, or end uses, provided by electricity could, potentially, be provided by hydrogen. The key to attaining the hydrogen vision, however, is not substitution but the “intra-changeability” of electricity and hydrogen. For example, electricity from wind energy can be used to make hydrogen that can store wind energy for use as a zero-emission fuel in fuel cells to power automobiles, or to generate electricity when the wind is not blowing. This intra-changeability can create sustainable, clean energy for all of these end uses.

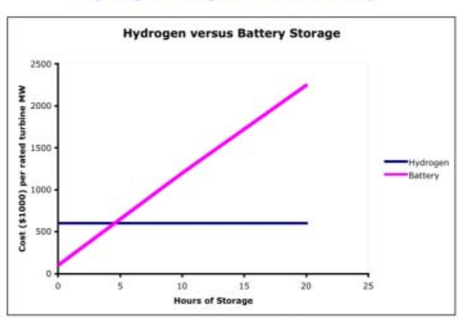
- Stationary – industrial, commercial and residential operations;
- Transport – movement on land (e.g., cars, trains), water, and air; and
- Portable – multiple small applications that can be easily carried.

Presently, the monetary value placed on electricity or hydrogen does not reflect the value of improved environmental quality and other societal benefits of developing energy currencies from renewable energy. National accounting systems (e.g., “gross national product” numbers) also do not value these benefits (or, conversely, recognize the adverse effects of environmental degradation, resource depletion, or health impacts) due to the use of energy currencies derived from fossil fuels). An important step toward a hydrogen economy will be for all countries (and appropriate Non-Governmental Organizations--NGOs) to address this difficult issue of adequately accounting for the monetary value of the benefits of renewable hydrogen deployment.

Resource Intermittency and Energy Storage

The main challenge, particularly with solar and wind renewable energy is resource intermittency. The sun does not shine all of the time and the wind does not blow at the same rate at any given location. To deal with the intermittency problem, a variety of energy storage systems have been developed. Most commonly, energy is stored in battery systems. Energy generated during a sunny day or a windy day can be used and/or stored for use later when the resources are not available. Production of hydrogen that can then be stored and used later as fuel is the important alternative to the storage forms in wide use today. As indicated in the example below, hydrogen storage is more economical than storage using batteries for other than short-term storage periods.

Hydrogen Storage of Wind Electricity



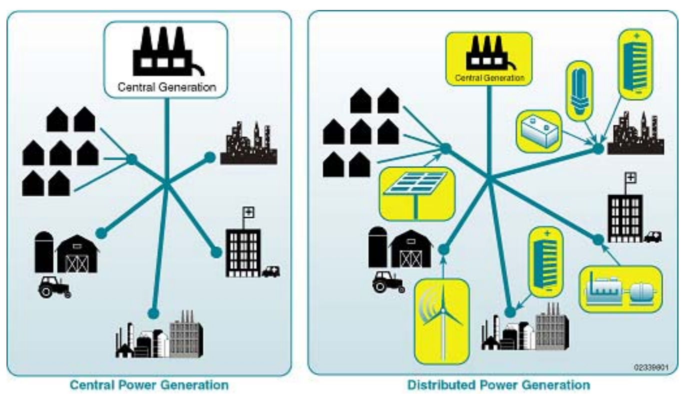
Assumes H2 storage @ $250/kg, electrolysis @ 250/kW, Pb acid batt. @ $100/MJ

Reference: Scott, Wind-PV Hydrogen by Electrolysis, Renewable Hydrogen Forum Report http://ases.org/

Distributed Generation Systems

In the conventional energy generation model, energy is generated at central generating stations, typically by large, fossil fueled power plants. However, large wind farms or multiple photovoltaic arrays could also serve as central generating stations. The electricity generated at these plants is then transmitted through power lines throughout a region. In distributed generation systems, the energy (both electrical and thermal) is generated closer to the point of use so that distribution lines are shortened and a variety of energy sources and generation technologies can be used, depending on the resources available and the load requirements of the energy users.

Renewable energy systems are particularly suited for distributed generation systems, as renewable energy resources tend to be "distributed" rather than "centralized" as fossil fuels tend to be. In this model, renewable energy electricity can be generated by large facilities like wind farms and concentrating solar energy plants or generated by small systems located to take advantage of available renewable resources and adjusted to best fit the local environmental and energy situation. There can also be a mix of renewable and fossil-fueled systems. A distributed energy system of interconnected generators, using a variety of energy sources, results in a much more robust power generation system that is less vulnerable to disruptions.



Central Power Generation   Distributed Power Generation

Renewable Energy "Power Packs"

Renewable energy "power packs" (RP^2) involve the coupling of renewable energy resources with zero-emission energy conversion technology in efficient, modular, site-defined power systems. One type of RP^2 could be an integrated renewable energy-based hydrogen fuel cell power system for distributed generation applications. Key technical issues to address in developing RP^2 technologies include:

- Creating RP^2 systems application templates for targeted prototypical residential, commercial, industrial, and other distributed generation markets
    - Module size(s)
    - Performance specifications
    - Cost targets
    - Thermal/electric/building-envelop integration
    - Resource assessment data requirements
- Systems design and integration
    - Technology (e.g., wind/electrolyzer/hydrogen storage/fuel cell) integration and optimization
    - Control systems

With the proper design RP^2 units can make energy available in even the most remote, off-grid locations in the world. Such units can power electronics for recreation, research, emergency home power, disaster relief, and multiple end-uses in remote areas that have no other access to power.

Key Role of Hydrogen

Hydrogen produced using renewable energy becomes key in solving the intermittency problems of renewable energy generation. The important union of renewable energy and hydrogen enhances the value and usefulness of renewable energy throughout the world.

25-Years of Progress through the IEA Hydrogen Implementing Agreements

Groups from around the world are coming together to make the renewable hydrogen vision a reality. Many partnerships have been formed and a number of forums have already come together to discuss and work together on implementation strategies. Case studies from regions and nations in many different locales are providing useful examples of successful strategies that are already underway. Over the past 25 years, much progress toward a hydrogen future has been made through the IEA Hydrogen Implementing Agreements (HIAf).

International Energy Agency
Agence Internationale de l'Energie

An intergovernmental body committed to advancing security of energy supply, economic growth and environmental sustainability through energy policy co-operation

International Energy Agency (IEA)

The International Energy Agency (IEA) was established in 1974, following the first oil crisis, for the purpose of facilitating collaborations for the economic development, energy security, environmental protection, and well-being of its members and of the world as a whole. For more than 20 years, the IEA has supported collaborative activities focused on the advancement of hydrogen technologies.

The IEA brings together policy-makers and experts from its 26 Member countries:

Australia	France	Korea	Sweden
Austria	Germany	Luxemburg	Switzerland
Belgium	Greece	Netherlands	Turkey
Canada	Hungary	New Zealand	United Kingdom
Czech Republic	Ireland	Norway	United States
Denmark	Italy	Portugal	
Finland	Japan	Spain	

The IEA serves as a forum to discuss common energy technology issues, to undertake studies, and to organize workshops that assist Members with technology policy development. An IEA Framework is provided for more than 40 international collaborative energy research, development and demonstration projects known as Implementing Agreements. Hydrogen is a major part of the IEA efforts.

As is discussed on the IEA web site http://www.iea.org/, hydrogen is rapidly emerging as a major component of clean sustainable energy systems. It is relevant to all of the energy sectors—transportation, buildings, utilities, and industry. In addition concerns about global climate change and energy security create the forum for mainstream market penetration of hydrogen. Ultimately, hydrogen and electricity, the two major energy carriers, will come from sustainable energy sources, although fossil fuel will likely remain a significant and transitional resource.

The IEA points to a number of case studies involving hydrogen development projects throughout its member countries. These can be obtained from the following United States (U.S.) Department of Energy web site: http://www.eere.energy.gov/hydrogenandfuelcells/hydrogen/iea/case_studies.html

In addition, the IEA has produced a substantial review of renewable energy markets and trends in the IEA countries. The aim of this work is to identify best practices in order to assist governments in making energy policy decisions in the future. http://www.iea.org/dbtw-wpd/bookshop/add.aspx?id=177

Hydrogen Implementing Agreements

The IEA hydrogen agreement states that." hydrogen could well become the major component of clean sustainable energy systems in the longer term. It is relevant to all of the energy sectors - transportation, buildings, utilities, and industry. Hydrogen can provide storage options for intermittent renewable technologies such as solar and wind, and, when combined with emerging decarbonisation technologies, can reduce greenhouse gas emissions from continued fossil fuel utilisation."

The vision of the IEA Implementing Agreement on Hydrogen Production and Utilisation is one of clean sustainable energy supply of global proportions that plays a key role in all sectors of the economy. To achieve this vision, the work of the Agreement is directed towards the development of advanced technologies, including direct solar production systems and low-temperature metal hydrides and room-temperature carbon nanostructures for storage.

Participating countries in the IEA-HIAf are Canada, European Commission, Iceland, Italy, Japan, Lithuania, Netherlands, Norway, Spain, Sweden, Switzerland, Turkey, United Kingdom, and the U.S.

Fuel Cell Agreements

As is stated in the fuel cell agreement, "fuel cells have the potential to convert fuels to electricity at very high efficiencies compared with conventional technologies. In addition to reductions in emissions of greenhouse gases resulting from the increased efficiency, their use does not result in the production of the other noxious emissions that are usually associated with combustion." (http://www.ieafuelcell.com)

The objectives of the Implementing Agreement on Advanced Fuel Cells are to advance the state of understanding of Participants in the field of advanced fuel cells through co-operative research, technology development and system analysis on fuel cell systems. There is a strong emphasis on information exchange through meetings, workshops and reports.
.
Participating countries are Australia, Belgium, Canada, Denmark, Finland, France, Germany, Italy, Japan, Korea, Netherlands, Norway, Sweden, Switzerland, United Kingdom, and the U.S.

Introduction to the International Partnership for the Hydrogen Economy (IPHE)

IPHE INTERNATIONAL PARTNERSHIP FOR THE HYDROGEN ECONOMY

The main purpose of the IPHE, created in November 2003, is to serve as a mechanism to organize and implement effective, efficient, and focused international research, development, demonstration and commercial utilization activities related to hydrogen and fuel cell technologies. It also provides a forum for advancing policies, and common codes and standards that can accelerate the cost-effective transition to aglobal hydrogen economy to enhance energy security and environmental protection. (http://www.iphe.net/)

The IPHE Partners members include:

Australia	European Commissions	India	Republic of Korea
Brazil	France	Italy	Russian Federation
Canada	Germany	Japan	United Kingdom
China	Iceland	Norway	United States

The IPHE provides the following functions:

- Identifies and promotes potential areas of bilateral and multilateral collaboration on hydrogen and fuel cell technologies;
- Analyzes and recommends priorities for research, development, demonstration, and commercial utilization of hydrogen technologies and equipment;.
- Analyzes and develops policy recommendations on technical guidance, including common codes, standards and regulations, to advance hydrogen and fuel cell technology development, demonstration and commercial use;
- Fosters implementation of large-scale, long-term public-private cooperation to advance hydrogen and fuel cell technology and infrastructure research, development, demonstration and commercial use, in accordance with Partners' priorities;
- Coordinates and leverage resources to advance bilateral and multilateral cooperation in hydrogen and fuel cell technology research, development, demonstration and commercial utilization; and
- Addresses emerging technical, financial, legal, market, socioeconomic, environmental, and policy issues and opportunities related to hydrogen and fuel cell technology that are not currently being addressed elsewhere.

The hydrogen energy vision, as described by the IPHE, is that energy systems of the future must be cleaner, and much more efficient, flexible, and reliable to meet the growing global demand for energy. A hydrogen economy offers a potential solution to satisfying the global energy requirements, while reducing (and eventually eliminating) carbon dioxide and other greenhouse gas emissions and improving energy security.

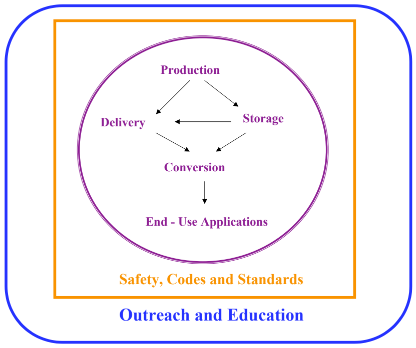
The IPHE provides information on a number of activities going on in the member countries (http://www.iphe.net/ipheinternationallinks.htm). It also provides information on national hydrogen roadmaps and policies (http://www.iphe.net/ipheroadmaps.htm).

In the IPHE's meeting September 2004, delegates from around 20 countries met in Reykjavik to discuss boosting use of hydrogen energy. Participants agreed on an action plan to develop scoping papers on production and storage of hydrogen, fuel cell applications, and codes and standards. The meeting also decided that IPHE should link with UN education programs to raise awareness of hydrogen's potential.

Renewable Hydrogen Energy Technology Development and Deployment Overview

The key elements of the renewable hydrogen system are:

- Production
- Delivery
- Storage
- Conversion
- End-Use Applications
- Safety, Codes and Standards
- Education and Outreach



Hydrogen is produced, delivered, and stored for multiple end uses. At each step, there are safety, codes and standards that need to be considered to ensure the highest quality and the safest procedures. Public awareness of all of these aspects of the hydrogen system is important to achieving the political concensus that is essential for successful renewable hydrogen technology development and deployment. In addition to the technical aspects of the hydrogen system, economics and the proper valuation of externalities (i.e., environmental and societal impacts) as well as policy environments are important factors determining success. These aspects are discussed in detail for the U.S. elsewhere (e.g., National Hydrogen Energy Roadmap, www.eere.energy.gov/hydrogenandfuelcells/pdfs/national_h2_roadmap.pdf).

Production

About 95% of the hydrogen used today comes from reforming natural gas. The remainder, high-purity hydrogen from water electrolysis, is produced using electricity that is mainly generated by burning fossil fuels. Some of the specific technologies used to produce hydrogen include:

- **Steam reforming** converts methane (and other hydrocarbons in natural gas) into hydrogen and carbon monoxide by reaction with steam over a nickel catalyst;
- **Electrolysis** uses electrical current to split water into hydrogen at the cathode (+) and oxygen at the anode (-);
- **Steam electrolysis** (a variation on conventional electrolysis) uses heat, instead of electricity, to provide some of the energy needed to split water, making the process more energy efficient;
- **Thermochemical water splitting** uses chemicals and heat in multiple steps to split water into its component parts;
- **Photoelectrochemical systems** use semi-conducting materials (like photovoltaics) to split water using only sunlight;
- **Photobiological systems** use microorganisms to split water using sunlight;
- **Biological systems** use microbes to break down a variety of biomass feedstocks into hydrogen;
- **Thermal water splitting** uses a very high temperature (approximately 1000°C) to split water; and
- **Gasification** uses heat to break down biomass or coal into a gas from which pure hydrogen can be made.

Production of hydrogen from renewable energy rather than from non-renewable fuels has a number of advantages, which will continue to enhance the viability of renewable hydrogen futures. Some of the major concerns with non-renewable fuels are:

- Air pollution (i.e., multiple hazardous air pollutants and carbon dioxide, the main greenhouse gas implicated in global change) associated with the use of the fossil fuels to create the electricity to produce hydrogen;
- Finite supply of and lack of equitable access to fossil fuel and nuclear resources;
- Geographically limited distribution of resources that can lead to energy insecurity and political conflict as countries vie for control of the resources;
- Security issues associated with nuclear fuel and the risk of the fuels being used for weapons; and
- Lack of equitable economic development and access to jobs due to inequitable access to resources.

Delivery

Hydrogen is currently transported by pipeline or by road via cylinders, tube trailers, and cryogenic tankers, with a small amount shipped by rail or barge. Hydrogen distribution via high-pressure cylinders and tube trailers has a range of 100-200 miles from the production facility. For longer distances of up to 1,000 miles, hydrogen is usually transported as a liquid in super-insulated, cryogenic, over-the-road tankers, railcars, or barges, and then vaporized for use at the customer site. Pipelines in the U.S. are limited to a few areas where large hydrogen refineries and chemical plants are concentrated, such as Indiana, California, Texas, and Louisiana. There are also hydrogen pipeline networks in Europe, for example, in the Ruhr Valley of Germany.

Storage

Hydrogen is the lightest element and has the highest energy content per unit of weight of any known fuel—52,000 British Thermal Units (Btu) per pound (LHV) or 120 kJ/gm. Its low volumetric energy density makes it challenging to store, especially on-board a vehicle, where it must meet stringent volume and weight requirements to achieve the 300-mile range of today's gasoline-fueled automobiles.

Hydrogen storage is a key enabling technology for the advancement of fuel cell power systems in transportation applications. Low cost, energy efficient off-board storage of hydrogen will also be needed for stationary and portable applications, and throughout the hydrogen delivery system infrastructure. For example, storage is required at hydrogen production sites, hydrogen refueling stations, and stationary power sites. Temporary storage may also be required at terminals and/or intermediate storage locations.

Hydrogen can be stored in a variety of ways, but for hydrogen to be a competitive fuel for vehicles, the hydrogen vehicle must be able to travel a comparable distance to conventional hydrocarbon-fueled vehicles. Today's state-of-the-art is 5000- and 10,000-psi compressed gas tanks and cryogenic liquid hydrogen cylinders for on-board hydrogen storage. Hydrogen can also be stored in advanced solid-state materials via reversible sorption processes or chemical reaction:

- Simple metal hydrides
- Complex metal hydrides and chemical hydrides
- Carbon materials

Conversion

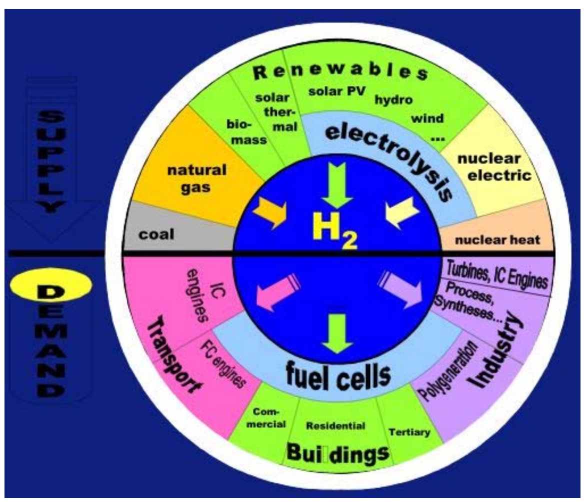
For the past 50 years, gaseous hydrogen has been used in large quantities as a feedstock in the petroleum refining, chemical, petrochemical, and synthetic fuels industries. Examples include making ammonia for fertilizer and removing sulfur in petroleum refining for such products as "reformulated" gasoline. Hydrogen is also used in the food processing, semiconductor, glass, and steel industries, as well as by electricity utilities to cool the rotor and stator coils in large turbine generators. Hydrogen also has a long history of use in both homes and factories as a fuel. In the 19th century, "coal gas," a mixture containing about 50% hydrogen, 26% methane, and other gases, including 7% carbon monoxide, was used extensively in Great Britain for lighting. In 1815, coal gas was distributed in London by a 48-km network of cast iron lines. In the U.S. prior to World War II, "town gas," a 50/50 mixture of hydrogen and carbon monoxide made by gasifying coal, was used by millions of Americans to cook food, light lamps, and heat water and homes. Today the National Aeronautics and Space Administration (NASA) in the U.S. is the only significant user of hydrogen as a fuel. The Space Shuttle's main engines are powered by liquid hydrogen and liquid oxygen, and hydrogen is also used onboard the Shuttle to power fuel cells that provide electricity and water. Through more than 40 years of experience in space travel, the closed-cycle loop of living months at a time on a space craft, yet not bringing months of water and energy supplies along, is ripe for application on earth.

Hydrogen can be converted into electrical and thermal energy through **thermochemical** (combustion engines and turbines) or **electrochemical** (fuel cells) processes. The main by-product of both processes is water, although there are small amounts of other emissions inherent in thermochemical processes. Fuel cells have the potential to revolutionize the way we use energy by offering a cleaner, more-efficient alternative to the combustion of gasoline and other fossil fuels. Hydrogen combustion engines are also being developed as hydrogen burns much "leaner" (i.e., are diluted with air) than gasoline or other fossil fuels, without the emissions of hydrocarbons, and with reduced oxides of nitrogen emissions.

End-Use Applications

The end uses of hydrogen are endless. It can be used to power the full range of stationary operations associated with industries and residences. It can be used to power all modes of transportation. It can be used in all kinds of portable devices.

These steps in the supply and use sides of the hydrogen system are summarized in the graphic below:



Source: European Commission Report of Hydrogen Energy and Fuel Cells
www.europa.eu.int/comm/research/energy/pdf/hydrogen_summary_report.pdf

Safety, Codes and Standards

Most countries in the world have established laws, codes, and regulations that require that products and systems being developed meet all applicable codes and standards to demonstrate that they are safe, perform as designed, and are compatible in systems use. Hydrogen is well known as a chemical, but its use as an energy carrier on a large-scale commercial basis is largely untested and undeveloped. To enable the commercialization of hydrogen in consumer products, new model building codes and equipment and other technical standards will need to be developed and recognized by national, state, and local governments.

In the international arena, the International Organization for Standardization (ISO) is a worldwide federation of national standards bodies from more than 140 countries. Established in 1947, its mission is to promote standardization to facilitate the exchange of goods and services, and to facilitate cooperation in intellectual, scientific, technological, and economic activities. ISO standards are developed through a consensus process. These are global solutions to satisfy industries and customers, and are based on voluntary involvement of interested parties.

The International Electrotechnical Commission (IEC) is the leading global organization for preparing and publishing international standards for all electrical, electronic, and related technologies. Its charter includes all electrotechnologies (including electronics, magnetics and electromagnetics, electroacoustics, multimedia, telecommunication); energy production and distribution; and general disciplines such as measurement and performance, dependability, design and development, safety, and the environment.

Within the U.N. framework, an agreement was signed in 1958, with contracting parties including most European countries, Australia, Japan, and South Africa to harmonize vehicle regulations. Standards developed under this agreement are presented to the contracting parties, which have two years to adopt them as national standards. Since the initial agreement, a new "accelerated" agreement was adopted under the U.N. framework in 1998, with most European countries, Canada, China, Japan, Korea, South Africa, and the U.S. as contracting parties to allow the development of global legal requirements for hydrogen vehicles. This new concept is termed Global Technical Regulations (GTRs). These regulations are essentially technical requirements; therefore, they allow the use of different approval processes and global harmonization of legal requirements for all vehicles.

Education and Outreach

A key factor in gaining public and governmental support for the hydrogen vision is education and outreach. Understanding the importance of generating hydrogen from renewable energy and appreciating the multiple benefits to society and the environment in using renewable hydrogen are key to successfully achieving the renewable hydrogen vision.

System Analysis and Economics

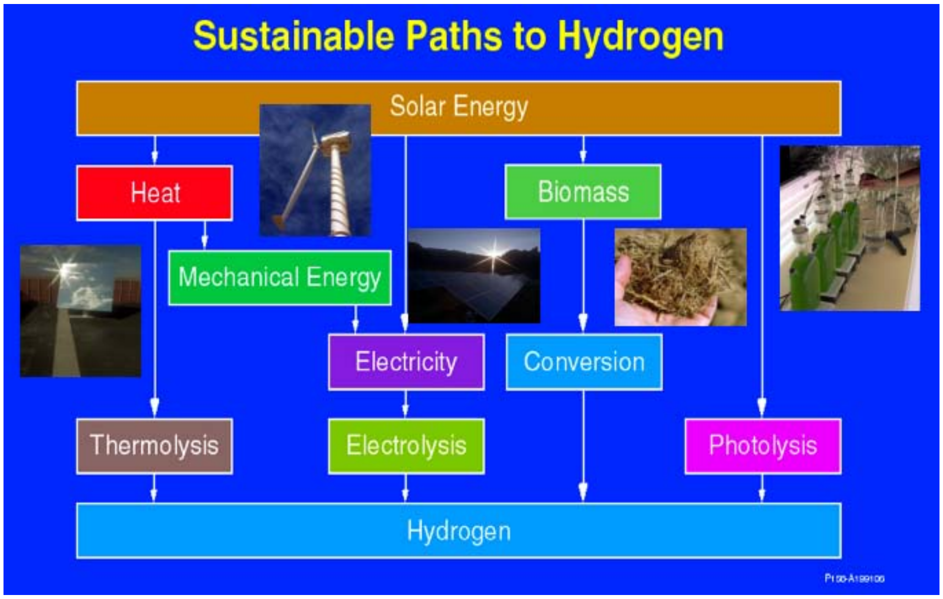
Creation of viable pathways to renewable hydrogen futures also is greatly influenced by the economics of development, and deployment and how environmental and social aspects, the externalities, are factored into decisions. Governments can help progress by adopting and supporting policies that encourage development and deployment of renewable energy-based hydrogen systems.

Systems analysis provides direction, focus, and support for the development and introduction of hydrogen production, storage, and end-use technologies, and provides a basis for recommendations on a balanced portfolio of activities. A variety of analysis methodologies should be used in combination to provide a sound understanding of hydrogen and fuel cell systems and markets from the basic resources required, to hydrogen production technology, to transportation and stationary applications. Realistic assumptions, both market- and technology-based, are critical to an accurate analytical study and in developing the common bases for analyzing alternatives at the system, technology or component level in terms of cost, performance, benefit, and risk impact.

The following sections go into much more detail on these elements of the renewable hydrogen energy technology development and deployment.

Renewable Hydrogen Energy—Production

Renewable hydrogen can be produced through a variety of pathways:



All energy ultimately comes from solar energy. The main pathways from solar energy to hydrogen, as is depicted in the overview graph above, are (from left to right):

- **Thermolysis** where heat (for example from concentrating solar power (CSP)) is used to split water directly using high temperature processes

- **Electrolysis** where the electricity used for the electrochemical hydrogen separation process is generated mechanically (from wind), electrolytically (from photovoltaics (PV)) or thermally (from CSP). Electrolyzers can produce hydrogen either at large central facilities or distributed at the point of use.

- **Pyrolysis** and catalytic reforming of biomass and post consumer residues such as plastics and trap grease to hydrogen

- **Photolysis** where sunlight is used to produce hydrogen directly through photobiological processes (such as genetically engineered algae) and photoelectrochemical processes where water is split directly by sunlight using specially engineered photovoltaic materials.

Of these pathways electrolysis, with wind and to a lesser extent PV as the energy source, is the most available and least costly option. On the other end of the scale, solar water splitting is a longer-term option.

Electrolysis

Currently, electrolysis provides only a small percentage of the world's hydrogen, most of which is supplied to applications requiring small volumes of high purity hydrogen (or oxygen, such as for breathing atmospheres for submarines). There is significant renewed interest in the use of electrolyzers to produce hydrogen as a fuel for automotive applications, with a number of refueling stations installed around the world. In addition, research continues in the integration of intermittent renewable resources (PV and wind) with electrolyzers, for producing hydrogen to be used as a fuel or for energy storage.

Water electrolysis is simply the splitting of molecules of water (H_2O) into hydrogen and oxygen (H_2 and O). Today, two types of electrolyzers are used for the commercial production of high-purity hydrogen—proton exchange membrane (PEM) and alkaline.

In a PEM water electrolyzer, a solid polymer membrane functions to both support the electrolysis reaction and to separate the gases. The proton exchange membrane conducts H+ ions (protons) directly through its highly stable, completely inert, solid polymer structure. This structure, typically comprised of a Teflon® backbone with sulfonic acid groups attached, passes the proton from one sulfonic acid group to the next, under the influence of an electromotive field, evolving hydrogen at the cathode. As hydrogen evolves, pressure is achieved by simply allowing hydrogen to accumulate within a confined volume to the desired pressure level. The PEM material has no known bubble pressure and is able to withstand high pressure (thousands of psi) when properly supported. (Source: Proton Energy Systems http://www.protonenergy.com/)

Electrolysis for hydrogen and oxygen requires very clean water. When alkaline water or seawater is electrolyzed, the products include sodium hydroxide and chlorine, with hydrogen as a by-product

Although electolyzers are a mature technology for producing hydrogen as a chemical product (e.g., refineries and fertilizer plants), reduced capital cost and increased system efficiency of electrolyzer systems will be required for these systems to be commercially viable in energy markets. Advanced electrolyzers designed to operate at high pressure and at high temperature could make these systems more cost-effective by eliminating the need for a compressor and reducing the electricity required to drive the electrolysis process. Integrated co-production of electricity and hydrogen from wind turbines and other renewable resources also offers some promising opportunities for improving the efficiency and economics of renewable hydrogen production using electrolysis.

A further promise of wind and PV/electrolysis arises from its capability to provide both fuel and power. Wind generation can power a town when the wind is blowing and solar energy can provide power when the sun is shining. Any excess power generated at these times can be used to produce hydrogen via electrolysis. When the wind is not blowing and the sun is not shining, stored hydrogen can be used to run an electrical generator and provide power to the town or to fuel vehicles.

Biomass

Biomass is already a widespread renewable energy source. Thermochemical conversion processes produce hydrogen from hydrocarbon and biomass-derived gases. Hydrogen can be produced via pyrolysis or gasification of biomass resources such as agricultural residues like peanut shells; consumer wastes including plastics and waste grease; or biomass specifically grown for energy uses. Biomass pyrolysis produces a liquid product (bio-oil) that contains a wide spectrum of components that can be separated into valuable chemicals and fuels, including hydrogen.

There is a need to separate the hydrogen from other gases and purify the hydrogen as part of these thermochemical conversion processes. Advanced separation technologies are being researched to reduce cost and to increase efficiency. Significant cost reductions can be achieved by combining separation and chemical reaction processes, thereby eliminating process steps and their associated capital and operating costs. Research efforts are being conducted to develop more durable separation materials, with reduced system capital costs.

Most of the hydrogen used today is produced by steam reforming of natural gas in large centralized reformers. However, a network of small-scale distributed production facilities may offer a viable approach for introducing hydrogen as an energy carrier. Distributed production requires less capital investment for the smaller volume of hydrogen needed initially, and does not require a substantial hydrogen transport and delivery infrastructure. One option now under investigation is the use of small-scale (i.e., 100 - 1,500 kg/day or 20 to 300 cars per day) distributed reformers that can produce hydrogen from natural gas or biomass-derived liquid fuels at the point of use, i.e., refueling stations and stationary power facilities.

Bio-derived liquids include ethanol, sugar alcohols, and "bio-oil". Bio-oils are produced from biomass resources—agricultural residues, consumer wastes, or biomass specifically grown for energy uses—via fermentation, gasification, or pyrolysis conversion processes. The reforming technology used to convert bio-derived liquids to hydrogen builds on the commercial processes used to reform natural gas today. Key research issues are to increase the efficiency and decrease the cost of hydrogen production. In particular, research is needed for better heat integration, durable and active reforming catalysts, efficient purification technology, efficient and low-cost, single-stage water-gas shift reactor technology, and other unit operation integration aspects.

Prototype Biomass Pyrolysis Unit

Biological Water Splitting

Certain photosynthetic microbes—green algae and cyanobacteria—produce hydrogen from water in their metabolic activities using light energy. In these photobiological systems, arrays of light-capturing antenna chlorophyll (Chl) molecules absorb sunlight, electron transport components convert light into chemical energy, and enzymes catalyze the dissociation of water to generate hydrogen and oxygen. Photobiological technology holds great promise, but because oxygen is produced along with the hydrogen, the technology must overcome the limitation of oxygen sensitivity in enzyme systems. In addition, the hydrogen production rate from photosynthetic microorganisms is currently too low for commercial viability. Furthermore, under bright sunlight, Chl antenna absorb much more light than can be utilized, resulting in the loss of up to 80% of the absorbed light. Researchers are addressing these issues by screening for naturally occurring organisms that are more tolerant of oxygen, creating new genetic forms of organisms that can sustain hydrogen production in the presence of oxygen, and increasing the light absorption and conversion efficiency of the microorganism. A new system is also being developed that uses a metabolic switch (sulfur deprivation) to cycle algal cells between a photosynthetic growth phase and a hydrogen production phase.Long-term R&D efforts will be required to fully understand and develop photobiological hydrogen production technologies.

Photoelectrochemical Water Splitting

Photoelectrochemical hydrogen production systems integrate a semiconducting material and a water electrolyzer into a single monolithic device, to produce hydrogen directly from water, using light as the only energy input. Simple in concept, the challenge is to find a material that can drive this one-step process. Two basic criteria must be met: the light-harvesting system must have suitable energetics to drive the electrolysis reaction; and the system must be stable and durable in an aqueous/electrolyte environment. Materials and components now in development build on the multijunction cell technology developed by the photovoltaic industry over the last 25 years. A variety of surface treatments are also being evaluated to address energetics requirements and corrosion. New catalysts for the water-splitting reactions are being designed. Research is underway to identify efficient, low cost materials and systems that are durable and stable in an aqueous environment.

Solar Thermochemical Water Splitting

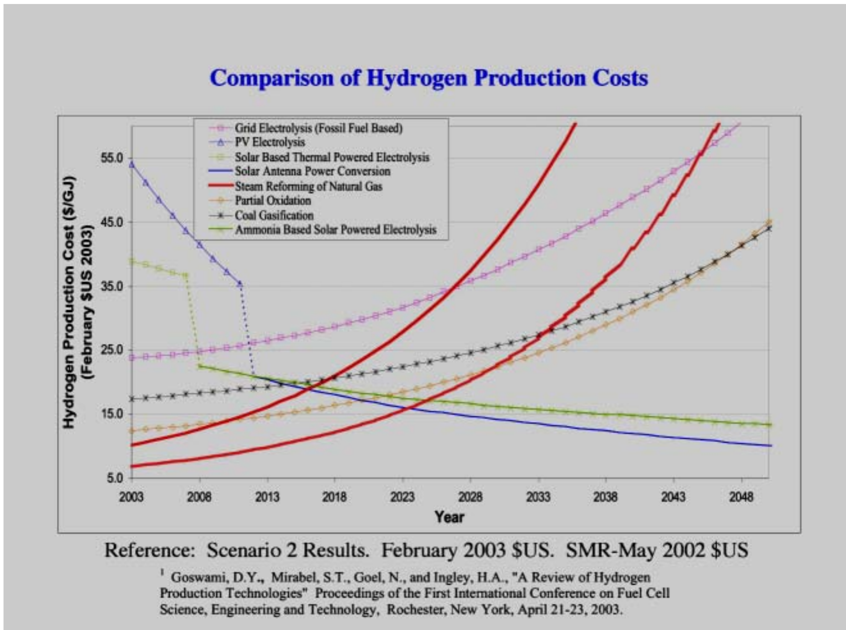
Concentrated solar energy can be used to generate temperatures of several hundred to over 2,000 degrees Celsius, at which thermochemical reaction cycles can be used to produce hydrogen from water (nuclear energy can also supply the needed high-temperature heat). These multi-step thermochemical cycles offer potentially attractive paths for generating hydrogen. Current R&D efforts are focused on understanding the kinetics and mechanisms of high-temperature chemical reactions and optimizing solar thermal reactor design concepts. Increased understanding of the underlying chemical mechanisms and advancements in technology could eventually lead to practical, direct, high-temperature, water-splitting processes.

Concentrating Solar Energy Unit

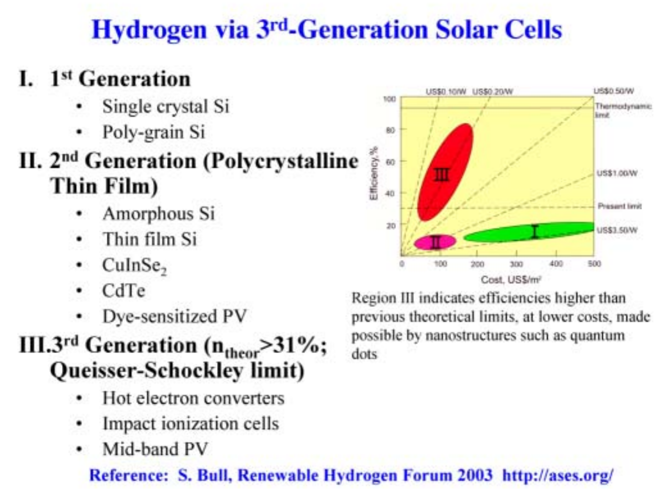
Comparison of Production Options

Costs. Recent analyses of the projected costs of different modes of hydrogen production through 2048 (see graph below) indicate that several of the renewable energy pathways will be the most economical even in the next decade. Renewable wind, geothermal, and hydro electricity-based electrolysis pathways, although not included in this study, also have a downward trend. In some markets where the electricity input is cheap enough, the renewable pathways are already beating out the fossil fuel pathways. This is the case in Iceland’s energy market where domestic renewables are cheaper alternatives to producing hydrogen than fossil fuels are.

In the analysis summarized here, capital (e.g., equipment, facility, technologies) and annual operating (e.g., feedstock, utilities, operation, maintenance, administration) costs plus variable feedstock costs, and new developments in solar thermal power and photovoltaics were taken into account. Using these cost comparisons, all of the fossil fuel-based production options are going up in costs, while the renewable energy ones are going down in costs.. It is important to note that no environmental or social benefit credits were given to renewable energy technologies, and that production options based on these renewable energy technologies would be even more cost-effective if additional credits were factored into the analysis.



Continuing developments in renewable energy technologies are expected to further reduce the costs, and improve the efficiencies. Solar energy is used to directly separate hydrogen and oxygen. Moving into 3rd generation solar cells, using nanostructures, is projected to dramatically increase the efficiency and lower the costs in the future. The figure below indicates the different solar cell materials that are being used, and are under consideration, shows the anticipated increases in efficiencies at decreasing costs. These technologies have the advantages of being modular in design; can be large or small; and mounted on rooftops, meaning that individuals could have their own hydrogen production system at their residence.



Energy Balances When it comes to making hydrogen, a fundamental issue is the amount of energy required to produce the hydrogen. Some energy is lost, regardless of the production method. Production of hydrogen from electrolysis currently is more efficient than production of hydrogen from techniques involving extraction of hydrogen from fossil fuels. If the electrolysis is fueled by fossil-based technologies, then additional energy is required is required to deal with the carbon dioxide and other pollution associated with fossil fuels. Similarly, the extra energy needed to deal with the same pollution by-products associated with making hydrogen directly from fossil fuels, using various extraction techniques, also must be taken into account in determining the overall energy loss resulting from production.

Hydrogen Energy—Delivery

As hydrogen demand grows, economies of scale will likely make centralized hydrogen production more cost-effective than distributed production. However, the economic viability of centralized production is tied to the development of a cost-effective method for hydrogen transport and delivery. Hydrogen is currently transported by road via cylinders, tube trailers, cryogenic tankers, and with some pipeline networks serving industrial users in parts of Europe and the U.S.. The delivery infrastructure for hydrogen will require efficient compressors for gaseous hydrogen, and liquefaction for cryogenic hydrogen; both currently have significant costs and inefficiencies associated with them. R&D is focused on developing advanced technologies to improve the energy efficiency, durability, and reliability of these systems. In addition, R&D is underway to investigate potential solid or liquid hydrogen carriers (e.g., metal hydrides, chemical hydrides, and solid nano-structures). Finally, R&D to evaluate the best materials for new pipelines and options for retrofitting existing natural gas pipelines is also underway.

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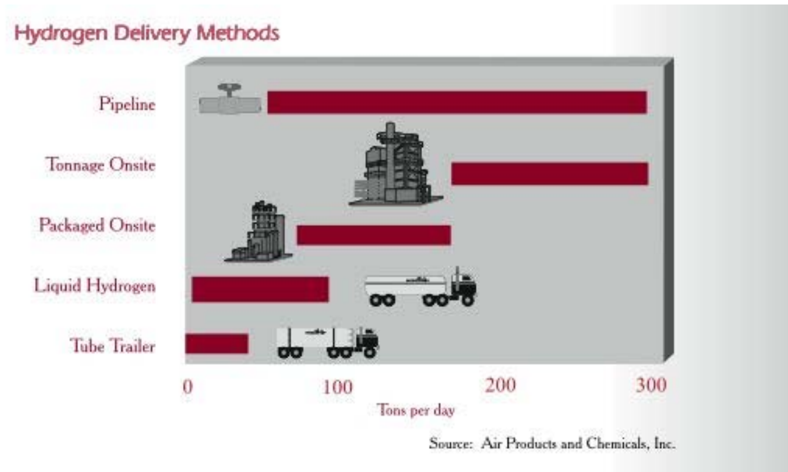
As demand increases, on-site production of hydrogen allows much larger quantities of hydrogen to be produced and used nearby, and may be a cost-effective way to meet high demands for hydrogen.

For areas having very high demand, pipelines can link consumers, with large centralized production plants that deliver large amounts of hydrogen. The chart below shows how delivery modes can be phased appropriately to meet demand.



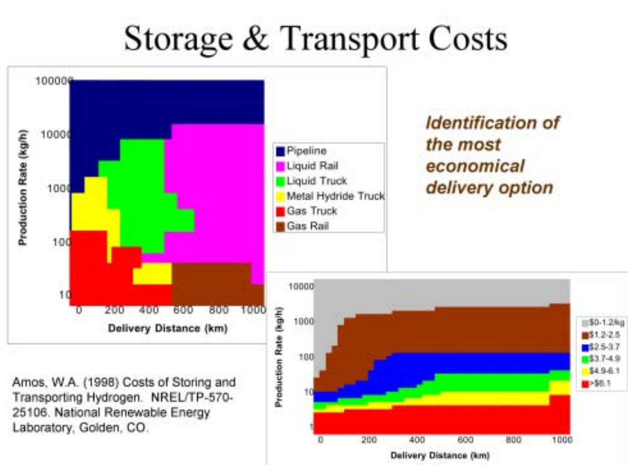
Hydrogen is usually distributed in pressurized cylinders and tube trailers to consumers within 100-200 miles from a production facility. For longer distances of up to 1000 miles, hydrogen is usually transported as a liquid in super-insulated, cryogenic, over-the-road tankers, railcars, or barges, and then vaporized for use at the customer site. Pipelines can carry gaseous hydrogen much longer distances.

Delivery Distances
Liquid Hydrogen Tube Trailers –100-200 miles
Liquid Hydrogen Tankers – 1000 miles
Gas Hydrogen Pipelines – > 1000 miles
Onsite – Long distance delivery not required

Source: **www.eere.energy.gov/hydrogenandfuelcells/pdfs/national_h2_roadmap.pdf**
National Hydrogen Roadmap

Another consideration regarding pipelines revolves around the relative cost of using pipelines to carry hydrogen, versus using transmission lines to carry electricity. In some cases it might be more efficient to use pipelines, and in other cases it might be better to transport the electricity.

The following chart shows the transport and associated storage costs for different options.



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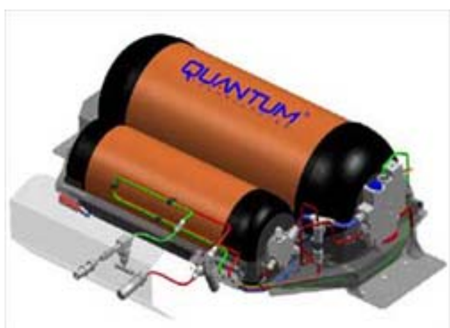
Hydrogen can be stored as a gas or liquid in bulk fuel tanks. Hydrogen being transported via pipelines also is effectively being stored in the pipelines until it is used, pressure and temperature differentials allowing for some flexibility in the amount stored. Hydrogen also can be stored in materials where the hydrogen is weakly bonded with hydrides (metallic or chemical) or adsorbed on carbon structures. Currently, hydrogen is most commonly stored in the liquid or gaseous form. Technologies to store hydrogen on materials is evolving.

The storage of compressed hydrogen gas in tanks is the most mature technology, though the volumetric density of hydrogen needs to be improved to make better use of limited space on board a vehicle. The energy density of gaseous hydrogen can be improved by storing hydrogen at higher pressures. This requires material and design improvements in order to ensure tank integrity. Advances in compression technologies are also required to improve efficiencies and reduce the cost of producing high-pressure hydrogen. The photo below shows an example of an advanced compressed gaseous hydrogen storage container for on-board vehicle use.



Compressed hydrogen tanks [5000 psi (~35 MPa) and 10,000 psi (~70 MPa)] have been certified worldwide according to ISO 11439 (Europe), NGV-2 (U.S.), and Reijikijun Betten (Iceland) standards and approved by TUV (Germany) and The High-Pressure Gas Safety Institute of Japan (KHK). Tanks have been demonstrated in several prototype fuel cell vehicles and are commercially available. Composite, 10,000-psi tanks have demonstrated a 2.35 safety factor (23,500 psi burst pressure), as required by the European Integrated Hydrogen Project specifications.

Advanced lightweight pressure vessels, with minimum permeation losses, have been designed and fabricated. These vessels use lightweight bladder liners that act as inflatable mandrels for composite overwrap and as permeation barriers for gas storage. These tank systems have demonstrated 12wt% hydrogen storage at 70 MPa (~10,000 psi).

The energy density of hydrogen can be improved by storing hydrogen in a liquid state. However, hydrogen losses become a concern and improved tank insulation is required to minimize losses from hydrogen boil-off. In addition, advances in liquefaction efficiencies are required to reduce the energy required to cool and liquefy hydrogen gas. The photo below shows a liquid hydrogen tank in use today on a hydrogen-fueled ICE vehicle.

Liquid tanks are being demonstrated in hydrogen-powered vehicles and a hybrid tank concept combining both high-pressure gaseous and cryogenic liquid storage is being studied. These hybrid insulated pressure vessels are lighter than hydrides; more compact than ambient-temperature pressure vessels; require less energy for liquefaction; and have less evaporative losses than liquid hydrogen tanks.

There are presently three generic mechanisms known for storing hydrogen in materials: absorption, adsorption, and chemical reaction:

- **Absorption.** In absorptive hydrogen storage, hydrogen is absorbed directly into the bulk of the material. In simple crystalline metal hydrides, this absorption occurs by the incorporation of atomic hydrogen into interstitial sites in the crystallographic lattice structure.
- **Adsorption.** Adsorption may be subdivided into physisorption and chemisorption, based on the energetics of the adsorption mechanism. Physisorbed hydrogen is more weakly bound energetically to the material than is chemisorbed hydrogen. Sorptive processes typically require highly porous materials to maximize the surface area available for hydrogen sorption to occur and to allow for easy uptake and release of hydrogen from the material.
- **Chemical reaction.** The chemical reaction route for hydrogen storage involves displacive chemical reactions for both hydrogen generation and hydrogen storage. For reversible hydrogen storage chemical reactions, hydrogen generation and hydrogen storage take place by a simple reversal of the chemical reaction as a result of modest changes in the temperature and pressure. Sodium alanate-based complex metal hydrides are an example. For irreversible hydrogen storage chemical reactions, the hydrogen generation reaction is not reversible under modest temperature/pressure changes, so that storage requires larger temperature/pressure changes or alternative chemical reactions. Sodium borohydride is an example.

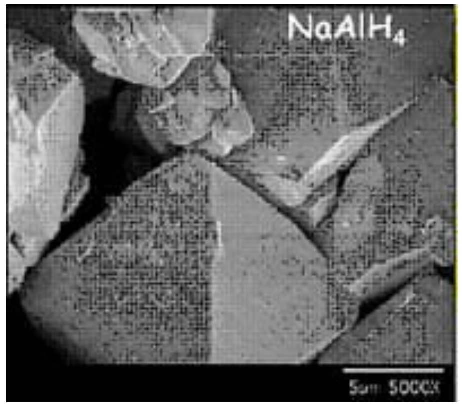
Currently, three classes of storage materials are being investigated:

- Metal hydrides - reversible solid-state materials regenerated on-board
- Chemical hydrides - hydrogen is released via chemical reaction (usually with water) and the byproduct hydride is regenerated off-board
- Carbon-based materials – reversible, solid-state materials are regenerated on-board.

Metal Hydrides (High and Low Temperature)

Various pure or alloyed metals can combine with hydrogen, producing stable metal hydrides. The hydrides decompose when heated, releasing the hydrogen. Hydrogen can be stored in the form of a hydride, at higher densities than by simple compression. Using this safe and efficient storage system depends on identifying a metal with sufficient adsorption capacity, operating under appropriate temperature ranges.

Conventional high capacity metal hydrides require high temperatures (300°-350°C) to liberate hydrogen, but sufficient heat is not generally available in fuel cell transportation applications. Currently existing low temperature hydrides, however, suffer from low gravimetric energy densities and require too much space on board or add significant weight to the vehicle. Alloying techniques have been developed that result in high-capacity, multi-component alloys with excellent kinetics, albeit at high temperatures. Today, alanates are considered to be the most promising of the complex metal hydrides studied for on-board hydrogen storage applications. Additional research is required to identify alloys with appropriate kinetics at low temperatures. The figure below shows the microstructure of sodium aluminum alanate.



Metal Hydride: Sodium Aluminum Alanate Microstructure

Chemical Hydrides

A chemical hydride slurry or solution can be used as a hydrogen carrier or storage medium. The hydrogen in the hydride is released through a reaction with water. Chemical hydride systems are irreversible and require thermal management and regeneration of the carrier to recharge the hydrogen content. There are two major embodiments of this approach.

In the first embodiment, a slurry of an inert stabilizing liquid protects the hydride from contact with moisture and makes the hydride pumpable. At the point of use, the slurry is mixed with water and the consequent reaction produces high purity hydrogen.

$$2LiH + 2H_2O \longrightarrow 2LiOH + 2H_2$$

An essential feature of the process is recovery and reuse of spent hydride at a centralized processing plant. Research issues include: the identification of safe, stable, and pumpable slurries; and the design of the reactor for regeneration of the spent slurry.

The second, and most advanced embodiment is sodium borohydride. The sodium borohydride is combined with water to create a non-toxic, non-flammable solution that produces hydrogen when exposed to a catalyst.

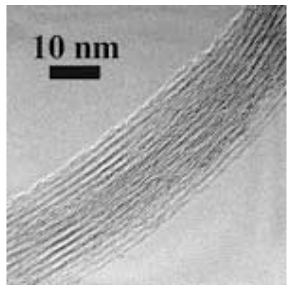
$$NaBH_4 + 2H_2O + \text{catalyst} \longrightarrow 4H_2 + NaBO_2$$

When the sodium borohydride solution and catalyst are separated, the solution stops producing hydrogen. After being in contact with the catalyst, the fuel is spent and goes into a waste tank. This waste is recyclable into new fuel. The borohydride system has been successfully demonstrated on prototype passenger vehicles such as the Chrysler Natrium.

Carbon-based Materials

Adsorption of hydrogen molecules on activated carbon has been studied in the past. Although the amount of hydrogen stored can approach the storage density of liquid hydrogen, these early systems required low temperatures (i.e., liquid nitrogen). Subsequent work showed that hydrogen gas can condense on carbon structures at conditions that do not induce adsorption within a standard mesoporous activated carbon.

Carbon materials present a long-term potential for hydrogen storage, and several carbon nanostructures are being investigated, with particular focus on single-wall nanotubes (SWNTs). However, the amount of storage and the mechanism through which hydrogen is stored in these materials are not well-defined. Fundamental studies are directed at understanding the basic reversible hydrogen storage mechanisms and optimizing them. The figure below is a photomicrograph of SWNTs.



Single-Wall Nanotube

Eventually, a selection of relatively lightweight, low-cost, and low-volume hydrogen storage devices will be available to meet a variety of energy needs. For example, pocket-sized containers will provide hydrogen for portable telecommunications and computer equipment; small and medium hydrogen containers will be available for vehicles and on-site power systems; and industrial-sized storage devices will be available for power parks and utility-scale systems. These hydrogen storage systems all will be efficient, durable, safe, and environmentally-friendly.

Hydrogen Energy—Conversion and End Use

Hydrogen can be converted to electrical, mechanical, and thermal energy in engines and in fuel cells. Engines can combust hydrogen in the same manner as gasoline or natural gas, while fuel cells use the chemical energy of hydrogen directly to produce electricity and thermal energy. Since electrochemical reactions do not require combustion to generate energy, fuel cells are inherently more efficient and cleaner than combustion engines.

The use of hydrogen in engines is a fairly well-developed technology. For example, hydrogen has been used in space shuttle main engines and unmanned rocket engines. Other combustion applications are under development, including new combustion equipment designed specifically for hydrogen in turbines and engines. Vehicles with hydrogen internal combustion engines (ICE) are now in the demonstration phase, and the combustion of hydrogen blends with natural gas is being tested. One example is the SunLine Transit CO. in California, where “Hythane”, a 20% hydrogen and 80% natural gas (methane) blend, has been demonstrated for several years in ICE bus fleets.

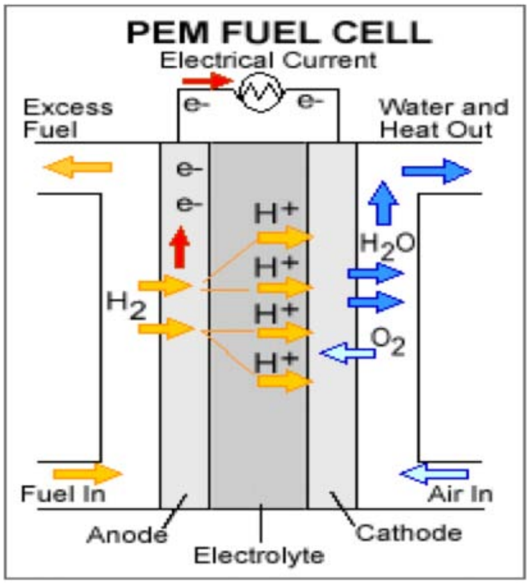
Fuel cells are an important enabling technology for the hydrogen economy and have the potential to revolutionize the way we power our nation, offering cleaner, more-efficient alternatives to the combustion of gasoline and other fossil fuels. Fuel cells have the potential to replace the internal combustion engine in vehicles and provide power in stationary and portable power applications because they are energy-efficient, clean, and fuel-flexible. Hydrogen or any hydrogen-rich fuel can be used by this emerging technology.

Today, fuel cells are being developed to power passenger vehicles, commercial buildings, homes, and even small devices such as laptop computers. Fuel cell systems can be extremely efficient over a large range of sizes (from 1 kW to hundreds of megawatts). Some systems can achieve overall efficiencies of 80% or more when heat production is combined with power generation. Fuel cell systems integrated with hydrogen production and storage can provide fuel for vehicles; energy for heating and cooling; and electricity to power communities in a single application. These clean systems offer a unique opportunity to integrate energy platforms, while also enabling energy independence, highly reliable energy services, and economic benefits.

Fuel cells are classified primarily by the kind of electrolyte they employ. This determines the kind of chemical reactions that take place in the cell, the kind of catalysts required, the temperature range in which the cell operates, the fuel required, and other factors. These characteristics, in turn, affect the applications for which these cells are most suitable. There are several types of fuel cells currently under development, each with its own advantages, limitations, and potential applications.

Polymer Electrolyte Membrane (PEM) Fuel Cells

Polymer electrolyte membrane (PEM) fuel cells—also called proton exchange membrane fuel cells—deliver high-power density and offer the advantages of low weight and volume, compared to other fuel cells. PEM fuel cells use a solid polymer as an electrolyte and porous carbon electrodes containing a platinum catalyst. They need only hydrogen, oxygen from the air, and water to operate and do not require corrosive fluids like some fuel cells. They are typically fueled with pure hydrogen supplied from storage tanks or on-board reformers.



Polymer electrolyte membrane fuel cells operate at relatively low temperatures, around 80°C (176°F). Low temperature operation allows them to start quickly (less warm-up time), and results in less wear on system components, resulting in better durability. However, it requires that a noble-metal catalyst (typically platinum) be used to separate the hydrogen's electrons and protons, adding to system cost. The platinum catalyst is also extremely sensitive to carbon monoxide (CO) poisoning, making it necessary to employ an additional reactor to reduce CO in the fuel gas if the hydrogen is derived from an alcohol or hydrocarbon fuel. This also adds to the cost. Developers are currently exploring platinum/ruthenium catalysts that are more resistant to CO.

PEM fuel cells are used primarily for transportation applications and some stationary applications. Due to their fast startup time, low sensitivity to orientation, and favorable power-to-weight ratio, PEM fuel cells are particularly suitable for use in passenger vehicles, such as cars and buses.

A significant barrier to using these fuel cells in vehicles is hydrogen storage. Most fuel cell vehicles (FCVs) powered by pure hydrogen must store the hydrogen onboard as a compressed gas in pressurized tanks. Due to the low energy density of hydrogen, it is difficult to store enough hydrogen on-board to allow vehicles to travel the same distance as gasoline-powered vehicles before refueling, typically 300-400 miles.

Higher-density liquid fuels such as methanol, ethanol, natural gas, liquefied petroleum gas, and gasoline can be used for fuel, but the vehicles must have an onboard fuel processor to reform the methanol to hydrogen. This increases costs and maintenance requirements. The reformer also releases carbon dioxide (a greenhouse gas), though less than that emitted from current gasoline-powered engines.

One disadvantage is that PEM are easily "poisoned" by carbon monoxide—carbon monoxide binds to the platinum catalyst at the anode, decreasing the fuel cell's efficiency. They are 85 percent efficient when used for the co-generation of electricity and heat, but less efficient at generating electricity alone (37 to 42 percent). This is only slightly more efficient than combustion-based power plants, which typically operate at 33 to 35 percent efficiency.

Direct Methanol Fuel Cells

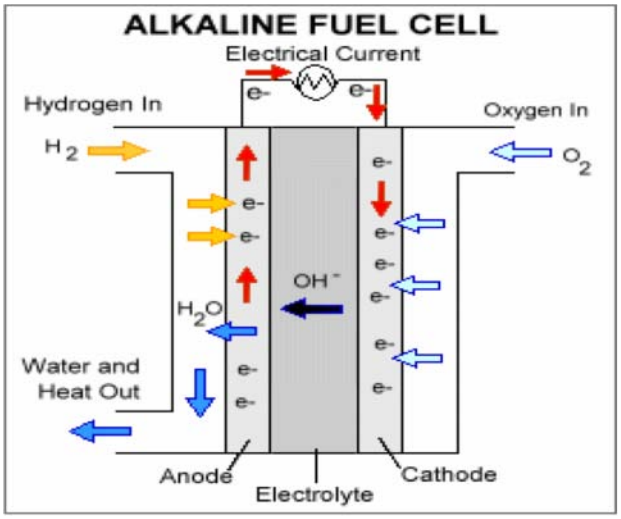
Most fuel cells are powered by hydrogen, which can be fed to the fuel cell system directly or can be generated within the fuel cell system by reforming hydrogen-rich fuels such as methanol, ethanol, and hydrocarbon fuels. Direct methanol fuel cells (DMFCs), however, are powered by pure methanol, which is mixed with steam and fed directly to the fuel cell anode.

Direct methanol fuel cells do not have many of the fuel storage problems typical of some fuel cells, since methanol has a higher energy density than hydrogen—though less than gasoline or diesel fuel. Methanol is also easier to transport, and to supply to the public using current infrastructure since it is a liquid, like gasoline is.

Direct methanol fuel cell technology is relatively new compared to that of fuel cells powered by pure hydrogen, and DMFC research and development are roughly 3-4 years behind that for other fuel cell types.

Alkaline Fuel Cells

Alkaline fuel cells (AFCs) were one of the first fuel cell technologies developed, and they were the first type widely used in the U.S. space program to produce electrical energy and water on-board spacecraft. These fuel cells use a solution of potassium hydroxide in water as the electrolyte and can use a variety of non-precious metals as a catalyst at the anode and cathode. High-temperature AFCs operate at temperatures between 100°C and 250°C (212°F and 482°F). However, newer AFC designs operate at lower temperatures of roughly 23°C to 70°C (74°F to 158°F)



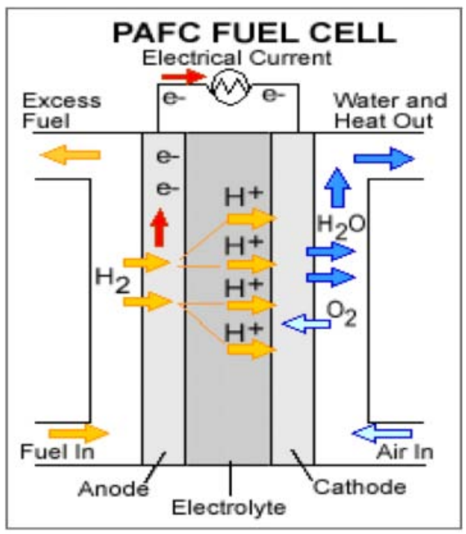
AFCs' high performance is due to the rate at which chemical reactions take place in the cell. They have also demonstrated efficiencies near 60 percent in space applications.

The disadvantage of this fuel cell type is that it is easily poisoned by carbon dioxide (CO_2). In fact, even the small amount of CO_2 in the air can affect this cell's operation, making it necessary to purify both the hydrogen and oxygen used in the cell. This purification process is costly. Susceptibility to poisoning also affects the cell's lifetime (the amount of time before it must be replaced), further adding to cost.

Cost is less of a factor for remote locations such as space or under the sea. However, to effectively compete in most mainstream commercial markets, these fuel cells will have to become more cost-effective. AFC stacks have been shown to maintain sufficiently stable operation for more than 8,000 operating hours. To be economically viable in large-scale utility applications, these fuel cells need to reach operating times exceeding 40,000 hours, something that has not yet been achieved due to material durability issues. This is possibly the most significant obstacle in commercializing this fuel cell technology.

Phosphoric Acid Fuel Cells

Phosphoric acid fuel cells use liquid phosphoric acid as an electrolyte—the acid is contained in a Teflon-bonded silicon carbide matrix—and porous carbon electrodes containing a platinum catalyst. The chemical reactions that take place in the cell are shown in the diagram below.



The phosphoric acid fuel cell (PAFC) is considered the "first generation" of modern fuel cells. It is one of the most mature cell types and the first to be used commercially, with over 200 units currently in use. This type of fuel cell is typically used for stationary power generation, but some PAFCs have been used to power large vehicles such as city buses.

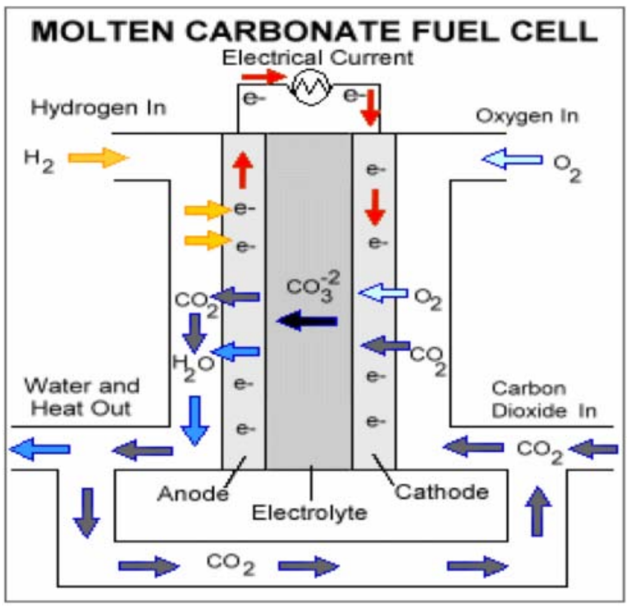
PAFCs are more tolerant of impurities in fossil fuels that have been reformed into hydrogen than PEM cells, which are easily "poisoned" by carbon monoxide—carbon monoxide binds to the platinum catalyst at the anode, decreasing the fuel cell's efficiency. They are 85 percent efficient when used for the co-generation of electricity and heat, but less efficient at generating electricity alone (37 to 42 percent). This is only slightly more efficient than combustion-based power plants, which typically operate at 33 to 35 percent efficiency. PAFCs are also less powerful than other fuel cells, given the same weight and volume. As a result, these fuel cells are typically large and heavy. PAFCs are also expensive. Like PEM fuel cells, PAFCs require an expensive platinum catalyst, which raises the cost of the fuel cell. A typical phosphoric acid fuel cell costs between $4,000 and $4,500 per kilowatt to operate.

Molten Carbonate Fuel Cells

Molten carbonate fuel cells (MCFCs) are currently being developed for natural gas and coal-based power plants for electrical utility, industrial, and military applications. MCFCs are high-temperature fuel cells that use an electrolyte composed of a molten carbonate salt mixture suspended in a porous, chemically inert ceramic lithium aluminum oxide (LiAlO2) matrix. Since they operate at extremely high temperatures of 650°C (roughly 1,200°F) and above, non-precious metals can be used as catalysts at the anode and cathode, reducing costs.

Improved efficiency is another reason MCFCs offer significant cost reductions over phosphoric acid fuel cells (PAFCs). Molten carbonate fuel cells can reach efficiencies approaching 60 percent, considerably higher than the 37-42 percent efficiencies of a phosphoric acid fuel cell plant. When the waste heat is captured and used, overall fuel efficiencies can be as high as 85 percent.

Unlike alkaline, phosphoric acid, and polymer electrolyte membrane fuel cells, MCFCs don't require an external reformer to convert more energy-dense fuels to hydrogen. Due to the high temperatures at which MCFCs operate, these fuels are converted to hydrogen within the fuel cell itself by a process called internal reforming, which also reduces cost.



Molten carbonate fuel cells are not prone to carbon monoxide or carbon dioxide "poisoning" —they can even use carbon oxides as fuel—making them more attractive for fueling with gases made from coal. Because they are more resistant to impurities than other fuel cell types, scientists believe that they could even be capable of internal reforming of coal, assuming they can be made resistant to impurities such as sulfur and particulates that result from converting coal, a dirtier fossil fuel source than many others, into hydrogen.

The primary disadvantage of current MCFC technology is durability. The high temperatures at which these cells operate and the corrosive electrolyte used accelerate component breakdown and corrosion, decreasing cell life. Scientists are currently exploring corrosion-resistant materials for components, as well as fuel cell designs that increase cell life without decreasing performance.

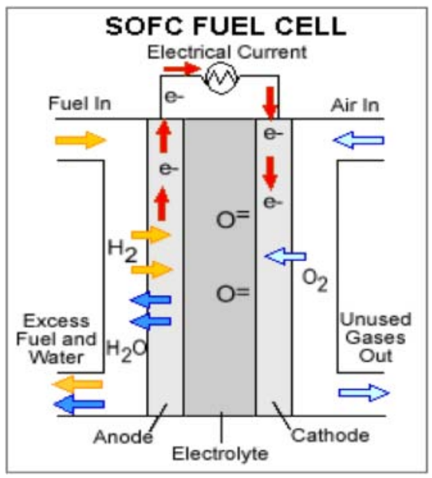
Solid Oxide Fuel Cells

Solid oxide fuel cells (SOFCs) use a hard, non-porous ceramic compound as the electrolyte. Since the electrolyte is a solid, the cells do not have to be constructed in the plate-like configuration typical of other fuel cell types. SOFCs are expected to be around 50-60 percent efficient at converting fuel to electricity. In applications designed to capture and utilize the system's waste heat (co-generation), overall fuel use efficiencies could top 80-85 percent.

Solid oxide fuel cells operate at very high temperatures—around 1,000°C (1,830°F). High temperature operation removes the need for a precious-metal catalyst, thereby reducing cost. It also allows SOFCs to reform fuels internally, which enables the use of a variety of fuels and reduces the cost associated with adding a reformer to the system.

SOFCs are also the most sulfur-resistant fuel cell type; they can tolerate several orders of magnitude more sulfur than other cell types. In addition, they are not poisoned by carbon monoxide (CO), which can even be used as fuel. This allows SOFCs to use gases made from coal.

High-temperature operation has disadvantages. It results in a slow startup and requires significant thermal shielding to retain heat and protect personnel, which may be acceptable for utility applications but not for transportation and small portable applications. The high operating temperatures also place stringent durability requirements on materials. The development of low-cost materials with high durability at cell operating temperatures is the key technical challenge facing this technology.



Scientists are currently exploring the potential for developing lower-temperature SOFCs, operating at or below 800°C, that have fewer durability problems and cost less. Lower-temperature SOFCs produce less electrical power, however, and stack materials that will function in this lower temperature range have not yet been identified.

Regenerative Fuel Cells

Regenerative fuel cells produce electricity from hydrogen and oxygen and generate heat and water as byproducts, just like other fuel cells. However, regenerative fuel cell systems can also use electricity from solar power or some other source to divide the excess water into oxygen and hydrogen fuel (i.e., "electrolysis"). This is a comparatively young fuel cell technology being developed by NASA and others.

Fuel Cell Summary

In summary, fuel cells are in various stages of development. Current fuel cell efficiencies range from 40 to 50 percent at full power and 60 percent at quarter-power, with up to about 80-percent efficiency reported for combined heat and power applications. Polymer-electrolyte membrane fuel cells are being developed and tested for use in transportation, stationary, and portable applications. Interest in polymer-electrolyte membrane fuel cells has experienced a tremendous upsurge over the past few years, and most major automotive manufacturers are developing fuel cell cars. Phosphoric-acid fuel cells are the most developed fuel cells for commercial use. Many stationary units have been installed to provide grid support and reliable back-up power. Alkaline fuel cells have been used in military applications and space missions (to provide electricity and drinking water for astronauts). Currently they are being tested for transportation applications. Solid-oxide and molten-carbonate fuel cells are best for use in generating electricity in stationary, combined-cycle applications and cogeneration applications in which waste heat is used for cogeneration. Solid-oxide fuel cells may also be a good fit for auxiliary power applications, especially large trucks.

These applications and the range of end-uses are highlighted in the figures below.

Hydrogen Conversion Technologies and Applications

Technology	Application
Combustion	
Gas Turbines	■ Distributed power ■ Combined heat and power ■ Central station power
Reciprocating Engines	■ Vehicles ■ Distributed power ■ Combined heat and power
Fuel Cells	
Polymer Electrolyte Membrane (PEM)	■ Vehicles ■ Distributed power ■ Combined heat and power ■ Portable power
Alkaline (AFC)	■ Vehicles ■ Distributed power
Phosphoric Acid (PAFC)	■ Distributed power ■ Combined heat and power
Molten Carbonate (MCFC)	■ Distributed power ■ Combined heat and power
Solid Oxide (SOFC)	■ Truck APVs ■ Distributed power ■ Combined heat and power

Hydrogen Fuel Applications

From space shuttles
To buses and cars of today

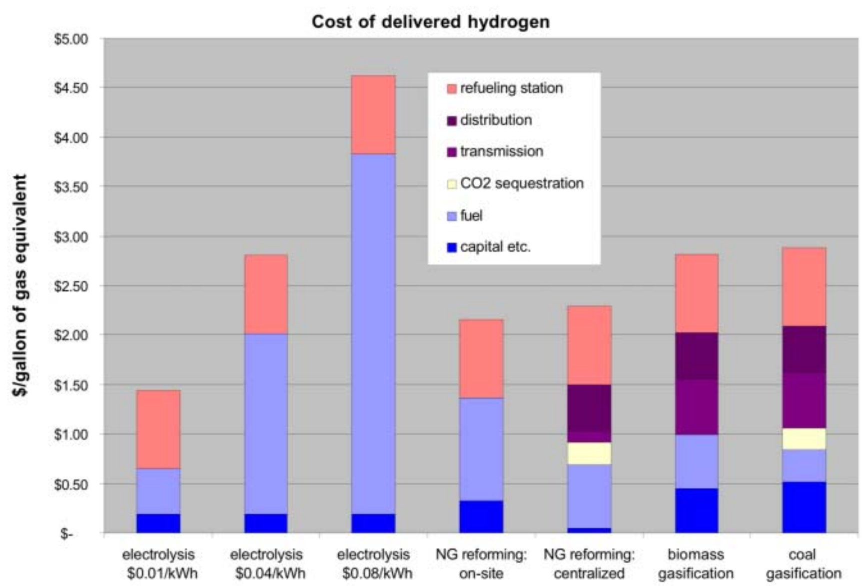
Other Applications

Comparing Hydrogen Supply Options

Delivered Costs

The following figure illustrates estimates of relative costs of delivered hydrogen using different production mechanisms. The first three options to the left represent renewable energy based electrolysis assuming three different fuel costs. The refueling station costs are the same for all of the options. Capital costs for the renewable electrolysis options are assumed to be the same. Additional costs for carbon sequestration are considered for two of the fossil fuel based options. It is clear from this illustration that the renewable hydrogen supply option becomes the most economical when the cost of the electricity drops. This is the case without even considering the many social and environmental costs associated with using fossil or nuclear fuels. A detailed survey of the costs of different hydrogen supply options is provided in a report (NREL/TP-570-27079, 1999).

Hydrogen Supply Options: Delivered Costs



Reference: Kartha, Renewable Hydrogen Forum Report

Emissions and Energy Requirements

The well-to-wheel analysis, illustrated below, takes into account energy use and emissions of greenhouse gas (GHG) emissions at every stage of the process from the moment the fuel is produced at the "well" to the moment the "wheels" move. In this study, several conventional fuels are compared to fuel cell hybrid vehicles (FCHV) using hydrogen produced by several methods, one of which is using renewable energy (i.e., wind electricity). The study concludes that the FCHV-wind electricity path is both the cleanest (i.e., GHG are negligible) and most energy efficient (i.e., it ties with the FCHV produced with natural gas). (www.hydrogenhighway.ca.gov/facts/einwelltowheel.pdf).

A Well-to-Wheel Analysis

Figure 1

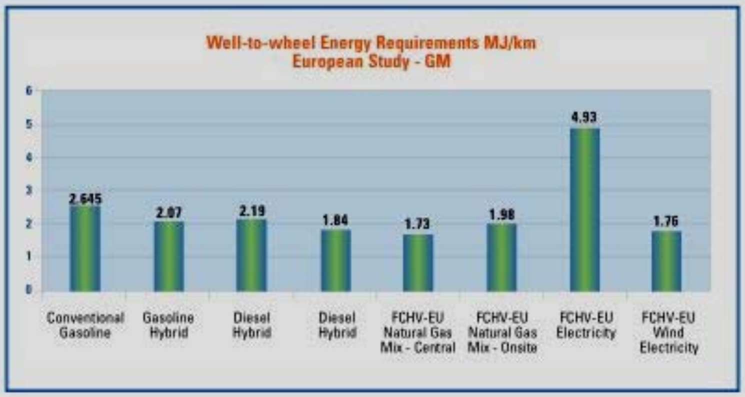
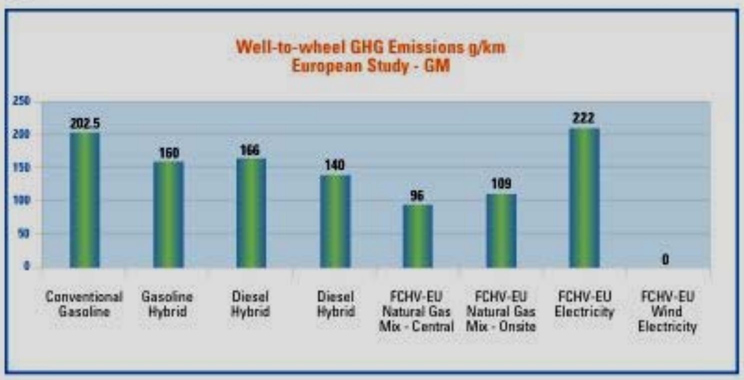
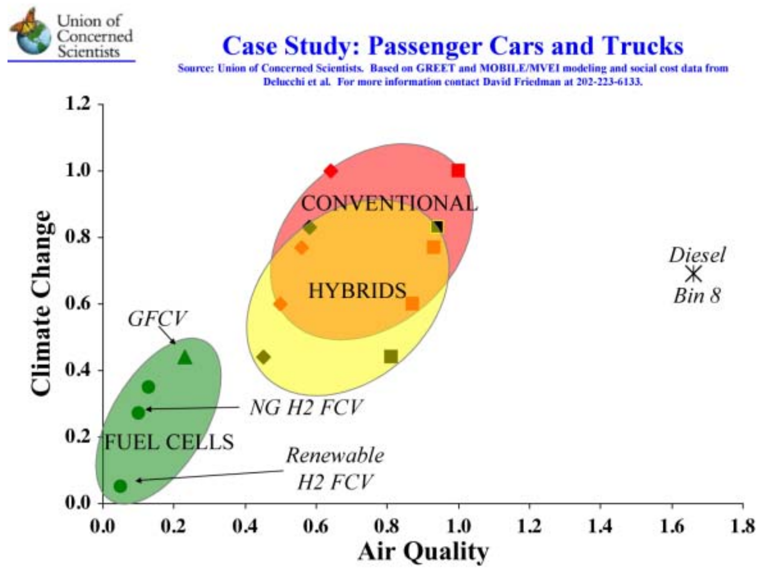


Figure 2



Air Quality and Climate Change

Another recent study examined the relative impacts of different vehicle emissions on climate change and air quality. As can be seen below, fuel cell vehicles (FCVs) have less impact than conventional and hybrid vehicles, and the fuel cell vehicles powered by renewable hydrogen are most benign. These renewable H2 FCVs have almost zero impact on both air quality and climate change.



Hydrogen Energy—Safety, Codes & Standards

The development and promulgation of codes and standards are essential if hydrogen is to become a significant energy carrier and fuel, because codes and standards are critical to establishing a market-receptive environment for commercializing hydrogen-based products and systems. A collaborative effort by government and industry is essential to prepare, review, and promulgate hydrogen codes and standards needed to expedite hydrogen infrastructure development. Creation and adoption of a harmonized set of national and international standards, codes, and regulations are essential for the safe use of hydrogen by consumers worldwide. Government-industry coordination can accelerate codes and standards processes. These discussions need to span national boundaries through such forums as the International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC) since codes and standards will need to be accepted by international bodies to achieve the needed global acceptance.

Codes and standards for the design, manufacture, and operation of hydrogen energy systems, products, and services are also essential for protecting producers and consumers and ensuring highest-quality products and services. Having codes and standards in place can also help dramatically speed the transitions from laboratory developments to the marketplace.

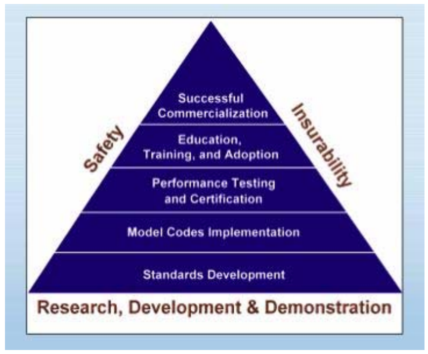
Current status of all codes and standards related to hydrogen and fuel cells is provided at http://www.fuelcellstandards.com/, a website created by the U.S. Department of Energy's Hydrogen, Fuel Cells and Hydrogen Technologies Program. These codes and standards are listed by application and by geographic location and organization, and also include international as well as individual country standards.

A review of codes and standards has been prepared by the Partnership for Advancing the Transition to Hydrogen (PATH) and is available at www.hpath.org/TechnicalReport.pdf. Current codes and standards for the United States, Japan and Canada, along with international standards, are discussed.

Some form of global technical regulations that deal with vehicles in particular will be needed, as these technologies progress. Since regulations are difficult to change once adopted, some note that any technological advances that do not conform to the regulations will not be commercially pursued. These important considerations will need to be part of the necessary international discussions.

Successful commercialization of safe, reliable hydrogen-based products and services will require development of standards, implementation of codes, testing and certification, and proper education and training. Highest quality research, development and demonstration are fundamental to this process.

Key Role of Hydrogen Codes and Standards



Hydrogen Energy—Education & Outreach

Strategic visioning is the key first step in the development of a renewable hydrogen future. Visioning allows a group, country or region to assess where they want to be and what they want to achieve.   A general common vision is to achieve energy security and the health and well-being of people and the environment.

From the visioning follows the development of a **roadmap**, setting up clear plans and concrete pathways to achieve the vision for that particular group. The roadmap outlines steps, based on an assessment of needs and available resources. Since resources and needs will vary from place to place, the particular steps for achieving the vision will vary. For example, in areas with excellent wind resources, the path to energy security would have wind as an important component.

Different countries and regions are in different phases of planning for a hydrogen future. Some like the European Union and the U.S. have already developed roadmaps and have projects underway. Other countries are just beginning. (i.e., IPHE http://www.iphe.net/ipheinternationallinks.htm)

Educating consumers, industry leaders, and public policy makers about the benefits of renewable hydrogen is critical to achieving a vision. The development and implementation of broad-based outreach and public education programs are important to building a political consensus to develop and implement roadmaps to a renewable hydrogen future.

A variety of approaches are being used to increase awareness and acceptance of renewable hydrogen, including coalition building, public relations and media campaigns; community demonstration projects; and long-term commitment of resources to public education systems.

To ensure success, consumers will need to understand the value and the relative risks of hydrogen; industry will need to work with other sectors and the media to create consumer demand for renewable hydrogen; and public policy makers will need to develop consistent and sustainable policies and regulations that support renewable hydrogen systems.

The internet itself is already providing a very valuable communication avenue for sharing information on all aspects of renewable hydrogen economy development.   Web sites are being used extensively to house valuable information on success stories from around the world.

Iceland provides one of the most striking examples of the role of public awareness in the development of a renewable hydrogen society. Almost the entire population is aware of and supports the transition to the renewable hydrogen economy.

Learning about the Renewable Hydrogen Vision Today

(For more examples, see hydrogen.com and nrel.gov)

Renewable Hydrogen Systems Economics

Achieving a renewable hydrogen future in any region is strongly influenced by the economics and the policy environments. The two are closely connected in that favorable policies can improve the economic viability of renewable hydrogen pathways.

Accounting for All of the Costs and Benefits

There are costs and benefits associated with all aspects of the hydrogen system. The costs of producing and using renewable hydrogen vary depending on the energy sources and technologies used to generate the hydrogen.

The costs of renewable energy generation are steadily dropping and, at present, wind energy is already competitive with fossil fuel energy generation. This is the case when just comparing technological development costs. When the environmental and social benefits (i.e., cost savings) of using the clean, zero-emission hydrogen fuel generated from renewable energy instead of fossil fuels are considered, the added value of renewable hydrogen dramatically increases.

In considering the development of renewable hydrogen systems in a region, it is important to consider the full set of multiple benefits that result from using renewable energy. When this is explicitly done, renewable hydrogen becomes a much more viable proposition, even in the short term.

Life Cycle Analyses (LCAs)

Full life cycle cost analyses include considerations of:

- Energy Cycle Requirements

- Greenhouse Gas Emissions
- Human and Environmental Health
- Other Environmental Consequences
- Energy Security
- Economic Growth, Diversity, and Sustainability
- Other Socioeconomic Consequences.

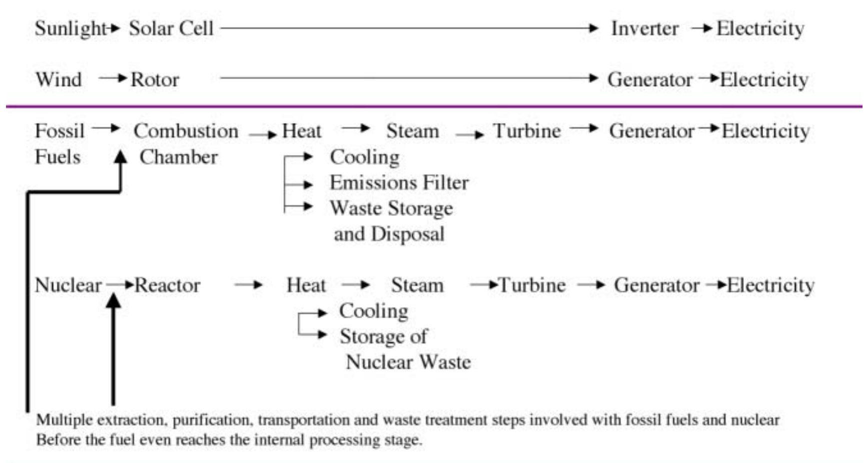
The first consideration, energy cycle requirements, include all aspects of the energy architecture (e.g., from acquisition of energy source to preparation for its use in hydrogen production) plus those of the development and deployment of hydrogen into end-uses. These are the elements that typically are considered when developing a "cost" of electricity or a "cost" of hydrogen associated with the energy source, be it a renewable energy or a non-renewable energy source.

The next six considerations are the side effects attributed to the use of the basic energy source and the associated system. These aspects typically are not formally included in the "cost" of the products and services derived from a particular energy source using a particular technology. In all of these six categories, renewable energy has considerable advantages over non-renewable energy.

Renewable energy does not contribute to greenhouse gas concentrations. Combustion of fossil fuels is the main source of carbon dioxide, which is the main greenhouse gas.

Renewable energy does not lead to emissions of air pollutants (e.g., sulfur and nitrogen oxides, volatile organic compounds, mercury and other toxics and fine particulates) and their chemical by-products (e.g., ozone, acids and aerosols). Combustion of fossil fuels are the main sources of these air pollutants, which have adverse effects on human health, visual air quality and the health of the environment.

In addition to the pollution factors involved in non-renewable fuels, these fuels also require multiple processing steps to convert the fuel to electricity. As is schematically shown below, renewable energy in the form of sunlight and wind are converted to electricity relatively directly and very cleanly while the processes for fossil fuels and nuclear are much more involved.



Processing Steps Involved in Renewable vs. Non-renewable Fuels

In addition to being renewable, these renewable fuels have a higher productivity potential since conversion is much more direct and much cleaner.

Reference: The Solar Economy H. Scheer

Use of non-renewable energy also has other environmental consequences related to land and water use. For example, coal fired power plants deplete water supplies in areas where they are operating. Recent studies in the western U.S. indicate that coal-fired power plants are significant competitors for water in arid regions.

Water shortage also has been noted as a possible side effect of hydrogen production via electrolysis. Recent assessments indicate that this effect is minor. As an example, the amount of water needed to power all of the cars in California on hydrogen is much less than 1% of the water used currently in the State of California. In areas like California where there is access to ocean water, desalinization could help manage

the water resources needed for hydrogen production. (Western Resources Advocates, The Last Straw http://www.westernresources.org/energy/;
Scott, 2003 and Mann, 2003 Renewable Hydrogen Forum, http://ases.org/)

Renewable energy--solar and wind--is a free resource and is available to everyone throughout the world. As a result, these are secure sources of energy. Fossil fuels, on the other hand, are owned. Acquisition of these fuels has been causing economic, political and environmental stresses around the world for decades.

Use of renewable energy creates more stable local and regional economies. The energy can be more easily produced and used locally. Jobs are created and the opportunities for enhanced sustainable development on all levels increases. As summarized in the table below, economic activity is more evenly distributed throughout a region for renewable energy development.

Regional distribution of ecoomic activitiy: renewable vs. non-renewable

	Heat and Electricity production from renewable sources, with energy storage	Biomass for energy and raw materials	Nuclear power and fossil fuels
Extraction	Not Applicable	Even	Uneven
Processing	Not Applicable	Even	Uneven
Storage	Even	Even	Uneven
Distribution	Even	Even	Even
Installation of generating Plant	Even	Even	Unveven
Operation of generating plant	Even	Even	Uneven
Maintance of generating plant	Evne	Evne	Uneven
Energy supply model	Even	Even	Uneven
Local/Regional tax revenues	Even	Even	Uneven
Regional provision of finance	Even	Even	Uneven

Referenece: The Solar Economy H. Scheer

Economic Viability

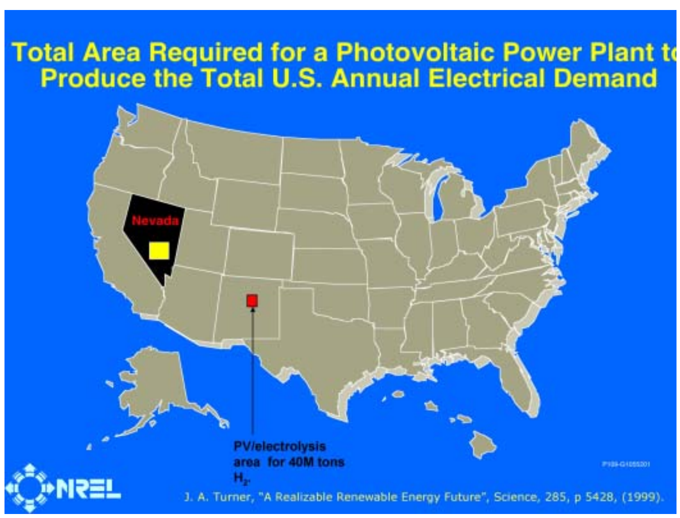
Renewable energy sources are becoming cost-effective, even when only a limited cost evaluation, which does not include externalities (i.e., environmental and societal values), are considered. This is the case for all of the renewable energy sources. One result of these cost savings is that renewable energy generation capacity is growing exponentially, in double digit figures, for both wind and solar applications.

Another example of viability is the cost of wind-generated hydrogen needed to fuel cars. In the Great Plains states of the U.S., where wind is an excellent resource, the fuel cost has been projected to drop to a few cents per mile. In the following example, an electricity cost of \$0.03/kW is assumed resulting in fuel prices that are comparable to current gasoline prices.

It is also illustrative to compare the amounts of different resources needed to supply hydrogen in large amounts. For example the current U.S. light duty vehicle fleet amounts to about 100 million vehicles. Since fuel cells are twice as efficient as current engines, it will take 40 million tons of hydrogen a year to fuel those cars.. To get 40 million tons of hydrogen to fuel100 million cars, it will take either:

- 95 million tons of natural gas (about a 20%) increase over the current US consumption;
- 310 million tons of coal (about a 30% increase over current consumption);
- 400-800 million tons of biomass (roughly equal to the residue and waste and some dedicated crops;
- Wind capacity just from the state of North Dakota; or
- 3,750 square miles devoted to PV solar panels.

The area of PV needed to produce 40 million tons and to supply all of the US electricity demand is indicated below.



The economics of renewable hydrogen are enhanced when the renewable energy is producing electricity and hydrogen in a complimentary fashion, as is illustrated by the scenarios below (Mann, 2003 Renewable Hydrogen Forum, http://ases.org/). Each example illustrates a different way that renewable energy can effectively produce electricity and hydrogen from the same facility. In the examples below, Scenario 2B produces the lowest-cost hydrogen. The purchase of non-peak electricity reduces the cost of the hydrogen despite the fact that the electrolzaer is not being operated full-time.

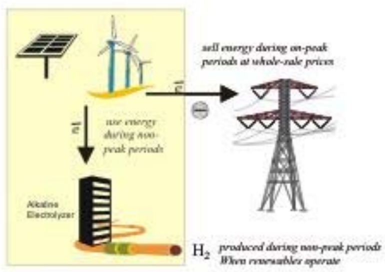


Figure 16. Scenario 1: Electricity Sold as Co-product during On-Peak Periods

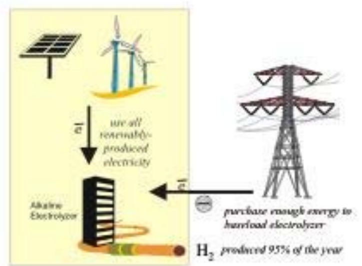


Figure 17. Scenario 2A: Hydrogen Produced from Renewable Electricity Plus Enough Grid Electricity to Baseload Electrolyzer

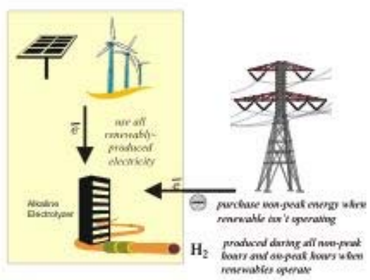


Figure 18. Scenario 2B: Hydrogen Produced from Renewable Electricity Plus Only Non-Peak Grid Electricity

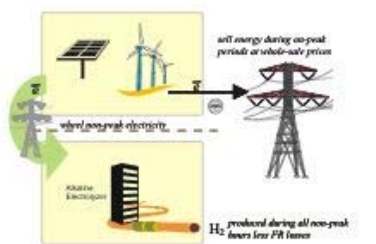
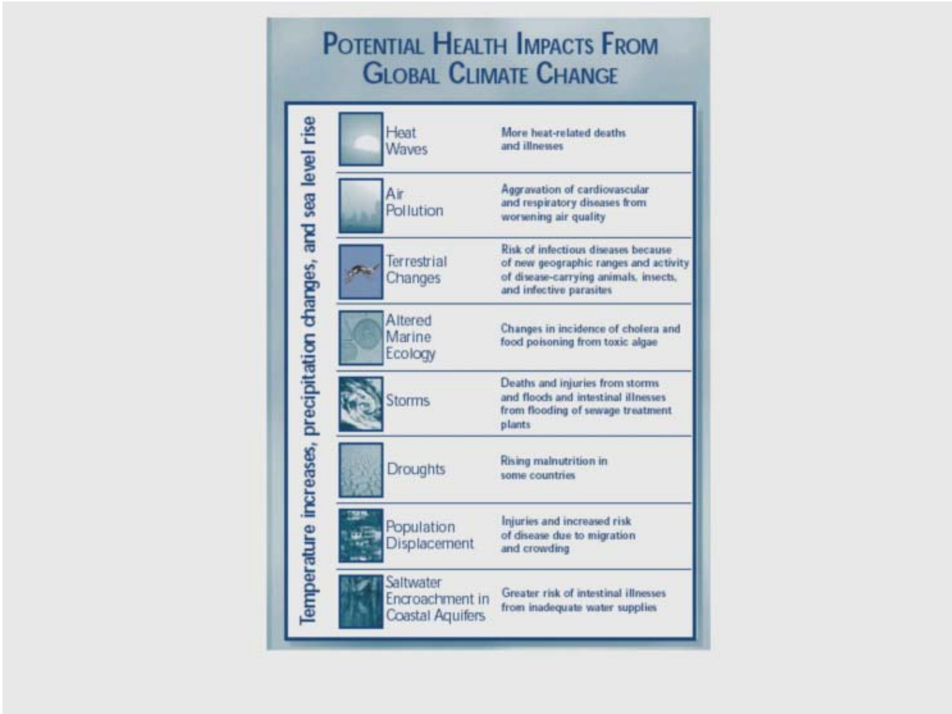


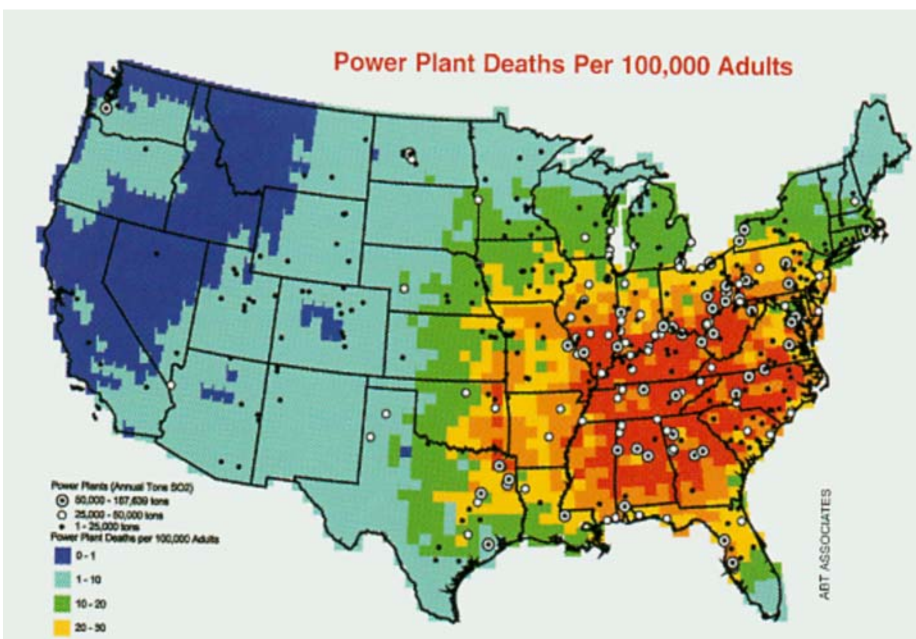
Figure 19. Scenario 3A: Hydrogen Production Decoupled from Renewables

Environmental and Societal Benefits of the Renewable Hydrogen Pathways

Use of renewable energy greatly reduces the impacts associated with emissions of greenhouse gases and other air pollutants. For example, some of the impacts associated with global climate change, which is directly related to increases in carbon dioxide, are noted below.

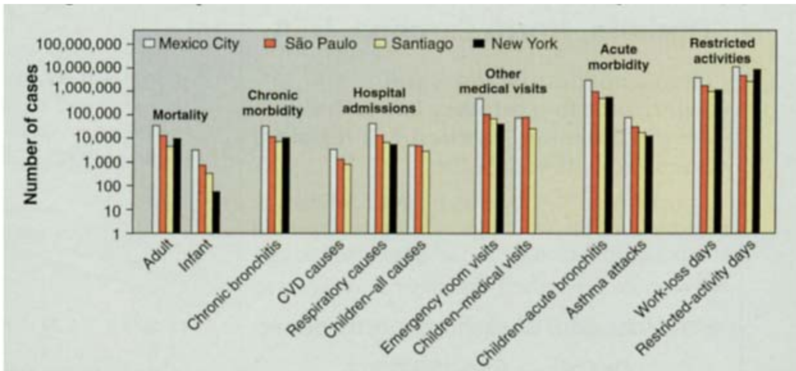


In addition to carbon dioxide, the key greenhouse gas, there are other air pollutant emissions that result from the combustion of fossil fuels. These pollutants give rise to human health impacts, degradation of scenes, and multiple damages to ecosystems. The following provides one illustration of the health impacts associated with coal-fired power plants. As is pointed out in the map below, regions with a high-density of coal-fired power plants and large population centers have the greatest health risks (red areas on the map).



The Particulate-Related Health Effects of Reducing Power Plant Emissions, ABT Associates Inc., October 2000, http://www.abtassoc.com/reports/particulate-related.pdf

Urban areas with a high density of fossil fuel power plants and vehicle usage are particularly vulnerable to air pollution impacts associated with use of these fuels. The example below provides one illustration of immediate multiple human health benefits that can result from decreasing the use of fossil fuels. Reduction in fossil fuels results in fewer emissions (i.e., emission of sulfur and nitrogen oxides--SO2 and NOX--and volatile organic compounds--VOCs) that lead to harmful fine particles and ozone, the key pollutants analyzed in the study.



Potential human health benefits from reductions in ozone and particulate matter air pollution associated with implementing GHG mitigation measures (2001–2020) (*18*). CVD, cardiovascular disease.

Environmental Health Perspectives Volume 109, Supplement 3, June 2001

Assessing the Health Benefits of Urban Air Pollution Reductions Associated with Climate Change Mitigation (2000-2020): Santiago, São Paulo, México City, and New York City

Luis Cifuentes, Victor H. Borja-Aburto, Nelson Gouveia, George Thurston, and Devra Lee Davis

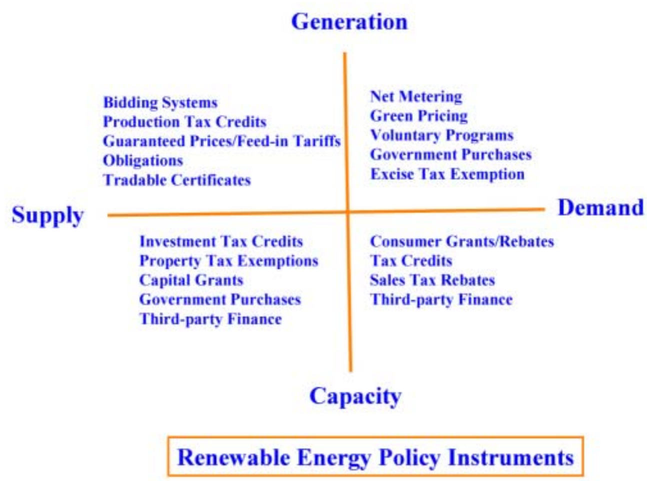
http://yosemite.epa.gov/oar/globalwarming.nsf/UniqueKeyLookup/SHSU5BUTG8/$File/mort_proj.pdf

Renewable Energy Policy Levers

Government policies can greatly help the development of renewable energy and hydrogen. For example, tax incentives, renewable portfolio standards (RPSs), and Non Fossil Fuel Obligations (NFFOs among other already are being used to improve the policy environments for renewable energy development..

A primary goal of these policies is to level the playing field for renewables relative to fossil-fuel-based technologies. Since the removal of traditional subsidies for conventional fuels can often be very challenging politically, the alternative is to provide a subsidy for renewables that can make them more competitive in the market place and also help to internalize the social benefits derived from their use. Although difficult to quantify, these “hidden” benefits of renewables, such as reduced harm to local environmental quality, human health, and global climate change; and improved energy security, as compared to conventional fuels, can assist in justifying these subsidies, and by many measures provide a net benefit to the country.

As has been pointed out in a recent IEA report (http://www.iea.org/dbtw-wpd/bookshop/add.aspx?id=177), these policy tools can be categorized into four quadrants based on the direction of their support. Policies can be directed towards consumers (demand-side) or producers (supply-side). They can also be directed towards capacity (i.e., the facility and/or its capital costs) or generation (i.e., the product and/or the associated price to the customer). Many of these policy tools are being used in countries throughout the world.



In addition to these policy instruments, there are regulatory or administrative procedures that are not financial in nature, but still contribute to the deployment of renewables. Additionally there are public awareness programs, also not finance-based, that support and encourage renewables.

Policies Addressing Supply and Capacity

Investment incentives are used to reduce the capital cost of deploying renewables. Tax policy is used to encourage production or to discourage consumption. On the production side, investment tax credits and property tax exemptions reduce tax payments for project owners. Government purchases also are a type of investment incentive to industries.

Policies Addressing Supply and Generation

Guaranteed price systems, feed-in tariffs (i.e., the regulatory minimum price a utility must pay an energy provider that is feeding renewable power into the grid) and preferential rates are all terms for tariffs at above-market rates. The price is usually paid for by either consumers or taxpayers through the utility.

Bidding systems such as the U.K.'s Non Fossil Fuel Obligation and Ireland's Alternative Energy Requirement (AER) scheme are based on competition for contracts to build projects with the lowest generation costs.

Most obligations are based on the final product such as kWh of electricity or quantities of liquid fuel, although some are based on capacity. Renewable energy portfolio standards, also known as quota systems, place an obligation on suppliers to provide a set quantity or percentage of their supply from renewable energy sources.

Renewable energy certificates (RECs) provide a mechanism to track and register renewable electricity production. These systems can be consistent with energy labeling.

Policies Addressing Generation and Demand

Green pricing is an optional utility service that gives customers an opportunity to support an increased level of utility company investment in renewables. Net metering arrangements (for example, these are already occurring in Denmark, Italy, the U.S., and Japan) also provide a form of guaranteed pricing, as customer-generators are credited for their electricity generation at the prevailing retail rate.

Tax policy also can be used to capture the externalities associated with energy production and consumption, such as environmental degradation and energy import dependence. For example, the Netherlands and Germany introduced a regulatory energy tax or "ecotax" on energy consumption. Renewable electricity consumption is exempt from the tax in the Netherlands. In addition a gasoline excise tax exemption allows liquid fuel refiners to offset the higher cost of including biofuels in gasoline blends.

Policies Addressing Demand and Capacity

In addition to supporting energy producers, investment incentives can also be used to reduce the capital cost of renewable energy technologies to end-users. With consumer grants and third-party finance, the government assumes risk by providing low-interest loans or bringing down the capital costs of renewables. For customer-owned systems, a tax credit or system rebate allows the owner to recover a portion of the up-front capital costs.

Other Measures

Planning and co-ordination is another area where government support can provide assistance to renewables. For example countries can support agencies that assist in renewables-related planning, resource assessment, and industry development. Public awareness programs encourage support for renewable energy. For example, energy labeling gives the public a clear understanding of the source of their electricity.

Successful Policy Examples—Focus on Asian Countries

Successful policy strategies to support renewables in the developing world have, in almost all cases, been underpinned by a national commitment or goal for the penetration of renewables in the national energy sector by a specific target year. Although often politically derived, a target or goal for renewables often helps to quantify the national commitment to renewables and sends a positive signal to the various market players that the government is committed to renewable energy for the long term.

These commitments have been taking many forms, such as through national policy papers (China, Philippines, Thailand, and Vietnam); through formal legislation (Korea, and the Philippines); or through other channels, such as sections of national plans for energy or economic development (India and Malaysia). Although these directives are not always complemented by a specific plan of action, they can serve as a valuable foundation for the evolution of national policies to support renewables.

Virtually all examples of the use of production tax credits are in developed countries. Thailand has established a competitive bidding process to award production subsidies to small renewable energy generators in the form of additional payments through power purchase agreements. In addition to Thailand, India is now also looking more closely at production-based incentives under their new electricity act ,as an alternative to the investment-based incentives that the country relied upon to support renewables in the 1990s.

Capital and investment subsidies to "buy down" the up-front cost of renewables have also been used extensively, particularly for smaller, off-grid applications like solar home systems, improved cook stoves, and solar water heaters. These techniques have been effective for off-grid systems in Thailand and Sri Lanka.

Another form of investment subsidies that have been commonly used in the developing world are tax incentives for newly installed capacity of non-conventional renewables. These forms of tax relief can include incentives related to personal or sales tax, accelerated depreciation, import duty waivers, and other related exemptions. They are being used in many markets. When strategically targeted, they can have a significant impact on renewable energy project development by lowering upfront capital costs for the developer. (NREL – Renewable Energy Compendium SARI-E Phase II / Sri Lanka, 2004 Draft)

Summary – Renewable Hydrogen Fundamentals

The renewable hydrogen vision is that eventually all regions of the world, including those that currently rely on non-renewable energy, will be part of the renewable hydrogen framework -- made possible by technological, economic and political advances -- that enables energy security, worldwide environmental quality and social equity. This vision is attainable.

Renewable hydrogen is technically available from a diverse array of technologies and distribution options. The marriage between hydrogen and solar/wind resources and technologies brings secure, clean energy—as well as making PV/wind a *"24-hour power"* option.

Wind energy is among the fastest-growing energy resources around the world, and has become cost-competitive with most conventional energy resources. This technology is highly suitable for use in hydrogen energy production in the many locations around the word where wind resources are adequate.

Concentrating solar power (CSP) is well-positioned for greater use, since it is a proven technology, relies on a resource that is abundant in many countries; and it has firm capacity, reliability and dispatchability, especially when coupled with hydrogen technologies. Biomass is already the world's fourth foremost fuel; it is a dispatchable resource and has a reasonable amount of capacity worldwide. The thermochemical path has the potential to achieve very high solar energy-to-chemical energy conversion efficiencies. Innovative technologies like use of algae, 3rd generation PV, direct splitting of water, and biological photovoltaics, also are promising.

Much progress is being made in the development of hydrogen storage materials, which are essential for maximizing the usability of hydrogen in a wide variety of applications. Advances in fuel cells also are accelerating the versatility of hydrogen applications. Progress on the development of hydrogen-powered vehicles continues to improve the viability of hydrogen transportation.

Development of international codes and standards are underway to help ensure highest quality and safety of hydrogen-based products and services worldwide. Educational programs also are helping raise public awareness of the multiple benefits of renewable hydrogen to the global society and the environment.

Economic viability of renewable hydrogen is greatly enhanced when the environmental and societal benefits of using renewable energy are taken into account. Recognition of these benefits needs to be translated into how energy is formally valued in individual countries and internationally. In some areas renewable wind, geothermal, and hydro electricity-based electrolysis pathways are already competitive with fossil fuel pathways. This is the case in Iceland's energy market where domestic renewable resources are cheaper alternatives to producing hydrogen than fossil fuels are.

Policies that provide economic incentives for renewable hydrogen in a variety of ways are enhancing progress.. Those policies that direct public funds and encourage private investors to direct their funds toward development of renewable hydrogen, public education programs, and renewable hydrogen research, development, and deployment programs also are helping to realize renewable hydrogen futures. International collaborations through multiple programs and forums are providing opportunities for accelerating this progress.

Progress toward a renewable hydrogen future is taking place around the world. International collaborations, through multiple programs and forums, are providing opportunities for accelerating this progress.

International Renewable Hydrogen Experience

Experiences from around the world are beginning to provide valuable insights into successful pathways to a renewable hydrogen future. The most extensive work is going on in Iceland. These efforts are presented as an example of how the transition to a renewable hydrogen economy is taking place for an entire country.

Renewable energy resource availability, effective use of the resources, political backing in the form of official roadmaps, economic policies, and commitment to research, development and deployment, public support, international cooperation and realization of the many limitations of fossil fuels are major elements in other renewable hydrogen success stories around the world. A few of the many examples are noted here. These examples are intended to illustrate the diversity of situations and activities around the world. They do not cover all of the work going on in the individual countries noted here.

In addition to the examples outlined here, which were largely obtained from the IPHE web site, additional country activities will be discussed during the workshop. The country and region experiences will be synthesized into a workshop follow-up document to help further future planning processes.

Iceland's Renewable Hydrogen Pathway

Iceland has already gone further than any other country in exploiting its abundant sources of renewable energy. Virtually all of its electricity and heating comes from hydroelectric power and the geothermal water reserves tapped from the hot rock layers lying just beneath the surface of this extraordinary island. However, with no fossil fuel resources of its own, the country relies on imported oil to power all its cars, buses and fishing trawlers, which provide 70% of its income. Use of fossil fuels has made Iceland the largest per capita producers of greenhouse gases in the world.

Iceland is now turning this around by converting its own renewable energy into a form that can power its own transport system, dramatically reducing the greenhouse and other harmful pollutant emissions and making its independence from fossil fuels complete.

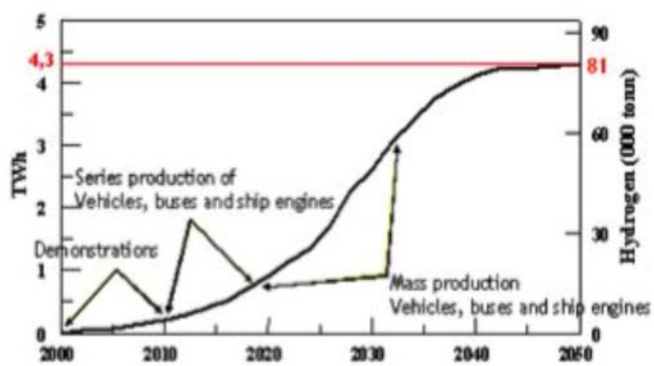
Iceland has already come a long way on its renewable hydrogen path. In addition to their long term commitment to and use of renewable energy, they have been doing research towards building a hydrogen society for the past 30 years, with implementation underway since 1998. The steps involve a mix of excellent and abundant renewable resources, research, dedicated energy policy, public awareness and support, favorable economics, and international cooperation. Some highlights are noted here:

- Three decades of hydrogen research beginning at the University of Iceland;
- Consultations between the University of Iceland and Hamburgische Electricitets Werke;
- Governmental Committee on domestic Fuel Production;
- Political Leadership – Governmental Policy on Hydrogen;
- Negotiations between Icelandic and Global Stakeholders on Hydrogen;
- Establishment of EcoEnergy & Icelandic New Energy ECTOS Project;
- Onwards— International cooperation through the EC, IEA, IPHE and others;
- 2003 (April)—Opening of the world's first hydrogen station built on the side of a conventional filling station;
- 2003 (October)—Testing of the operation of three hydrogen-powered buses commences; and
- 2003 On-going work efforts and consultation on hydrogen research programs and policy.

Iceland now has a six-phase plan for the continuing its introduction of a hydrogen economy:

- Demonstrations of operating hydrogen infrastructure and fuel cell buses in Reykjavik;
- Replacement of the Reykjavik city bus fleet, and possibly other bus fleets, with buses powered by fuel cells;
- Introduction of hydrogen based fuel cell private cars;
- Fuel-cell vessel demonstration and evaluation project;
- Replacement of fossil fuels in the fishing fleet by fuel-cell powered vessels; and
- Export of hydrogen to Europe.

Iceland's goal is to be a complete renewable hydrogen country within the next five decades. The timeline for this accelerated introduction of hydrogen vehicles is illustrated in the schematic below.



Estimated hydrogen transition of the transport and fishing fleet of Iceland
Total time is 50 years. Total energy needed is 4.3 TWh.
Total hydrogen needed is 81,000 tons.

A major element of the current Icelandic policy is to propose Iceland as an international platform for hydrogen research and testing. The policy has 5 main aspects:

- Favorable framework for business & research,
- International co-operation,
- Hydrogen research,
- Education and training; and
- Ongoing policy formulation.

This policy is a coherent part of Iceland's long-term policies on renewable energy and protection of the climate. Iceland alone is not able to take big steps in this area, but in cooperation with others, important further steps can be taken for

The most recognized hydrogen research project in Iceland is the ECTOS project – on Ecological City Transport System. The project was the first one in Europe of its kind, and has been used as a role model for similar projects in some other European countries. The partners, Daimler Chrysler, Shell Hydrogen, Norsk Hydro and Icelandic companies, with support from the European Union, and the U.S.. In this project, one sees clearly how important international cooperation is to the success of a national endeavor.

Iceland also is working on other projects – such as, the Euro Hyport on hydrogen transport to mainland Europe; a project on analyzing hydrogen infrastructure; and another project on developing the New Hydrogen Ship.

Iceland has been able to build up expertise and knowledge in the hydrogen area, including the following components:

- Start-up of hydrogen programs, projects and team-building
- International cooperation and links
- Knowledge on hydrogen infrastructure
- Economic and social research and values and hydrogen demonstration projects
- Hydrogen seminars, education, training materials and programs
-

These will be valuable elements to share with the rest of the growing hydrogen economy community.

Among the key attributes that are contributing to Iceland's successful transition to a renewable hydrogen future are:

- Use of excellent renewable geothermal and hydropower energy resources
- Renewable energy already the main source of electricity and heat demand;
- Public and policy maker awareness that continued use of oil to fuel transportation is not economically or environmentally acceptable;
- International cooperation to accelerate development and deployment of hydrogen within Iceland and to foster sale of Icelandic hydrogen to other countries;
- Detailed strategic plan of action for introducing demonstration projects;
- Solid research programs;
- Development of businesses aimed at accelerating the transition to hydrogen; and
- A clear vision of being the world's first hydrogen society, wholly based on a renewable energy.

(For additional information, for example, see Sigfusson, 2004).

Other European Countries: Norway, Germany, Netherlands, European Commission

Norway

Norway is a country already well-suited for the introduction of a renewable hydrogen economy. Almost all of Norway's electricity is produced by renewable water power. The electricity is relatively cheap compared to other countries. Petro (gasoline), on the other hand, is very expensive and highly taxed already. There are also high taxes on automobiles, except for the electric cars. This means that fuel cell vehicles are exempted from all taxes. These vehicles also do not pay tolls or parking fees, providing additional incentives for the hydrogen car.

Norway also has extensive experience with hydrogen and today is a leading producer of electrolysers. The only Norwegian manufacture of automobiles produces electric cars *–Ford's Think City Model*. Norway also has completed the first large-scale wind farm which converts wind energy directly to hydrogen. The system is located off the southwest coast of Norway on Utsira Island.

Some of the key factors favoring Norway's movement into the hydrogen economy are:

- Electricity produced almost totally by renewable energy;
- Electricity that is much cheaper than petroleum;
- Tax incentives for using non-petro-driven automobiles are already in place; and
- An abundance of additional renewable energy potential that can be used to produce hydrogen as well as electricity.

Germany

Global warming, resource depletion, general population dynamics, and energy consumption have been the main drivers for clean, sustainable, and renewable energy systems development in Germany. Much of the efforts have focused on research and demonstrations. Over the past decade Germany has had the largest number of E.U.-supported hydrogen activities of all of the E.U. countries. Among some of the solar hydrogen activities in Germany are: the Hysolar project in Stuttgart; Phoebus project in Julich; and the Solar House in Freiberg. Germany also is participating in a number of storage, refueling, testing, advertisement and licensing (http://www.eihp.org) operations for vehicles.

Germany is leading the world in demonstrations of hydrogen and fuel cell vehicles, hydrogen fueling stations, and the use of renewable energy to produce hydrogen from water through electrolysis.

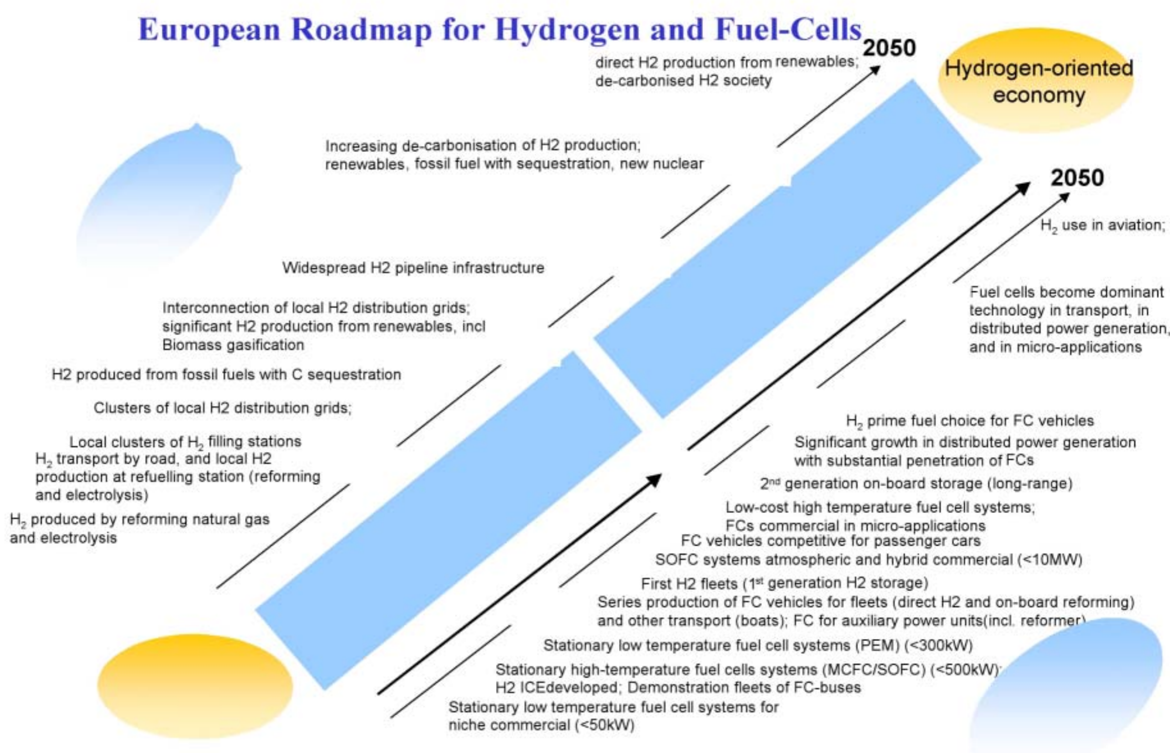
The Netherlands

The Netherlands is committed to a 22% reduction in energy use by Dutch industry; has a national energy vision with detailed scenarios until 2050; and has innovative projects to develop pathways towards that vision. There are fuel cell bus demonstration projects and hydrogen fueling stations already in place. The Netherlands also is working with Norway and Sweden on a project to integrate multiple hydrogen activities aimed at fostering the transition to renewable hydrogen.

Akzo Nobel and NedStack, producers and developers of fuel cells, are investigating the feasibility of a power plant based on fuel cells. The power plant will probably be built next to the chlorine electrolysis plant in Botlek, the Netherlands. With a peak capacity of 200 MW, it will be the world's largest fuel cell plant.

European Commission

The European Commission overall has an aggressive timetable for adoption of renewables, and now a renewed program for hydrogen technologies as well. As is summarized in the recent European Commission's comprehensive report, www.hynet.info/ecactiv/docs/highlg/hydrogen-report_en.pdf, there needs to be worldwide strategic planning and increased effort on research, development and deployment of hydrogen and fuel cell technologies. Considerable effort is already underway on all of these fronts in the E.C. The Commission's vision is to realize a step-by-step shift, towards a fully integrated hydrogen economy, based on renewable energy sources, by the middle of the century.



North and South America: USA, Canada and Brazil

United States

The active participation of the U.S. in the renewable hydrogen economy is reflected in considerable investments in R&D in fuel cells, hydrogen storage, vehicle and infrastructure and vehicle demonstrations, and education. In 2004 there was a total of $350 million in federal money; plus $225 million in private cost-sharing; and 30 awards including over 100 partners at universities, national energy labs, and industry. The awardees include many global, private sector partners.

In the fuel cell area, the United States is supporting the goal of reducing costs and improving durability by contributing $75 million in awards to13 firms and educational institutions in 12 states. In the storage area, the US has three "Centers of Excellence" for exploratory research in hydrogen storage. Each center includes a DOE national laboratory lead and several university and industry partners. There are an additional 14 individual projects focusing on new materials and analysis. The overall goal is to be able to store enough hydrogen to enable greater than a 300-mile driving range, without impacting cargo or passenger space. The DOE share for this National Hydrogen Storage Project is $150 million over five years, with an additional private cost share of approximately $20 million.

The vehicle and Infrastructure "learning " demonstration program includes $190 M with 50-50% cost-share, for a total of $380 M over six years. This will help DOE focus its research and development efforts, provide insight into vehicle and infrastructure interface issues, and will help address codes, standards and safety issues. In the outreach area, the "Hydrogen 101" program provides hydrogen education workshops for journalists, legislators, regulators and other policy-makers. The U.S. is also developing hydrogen curriculum for middle school and high school students.

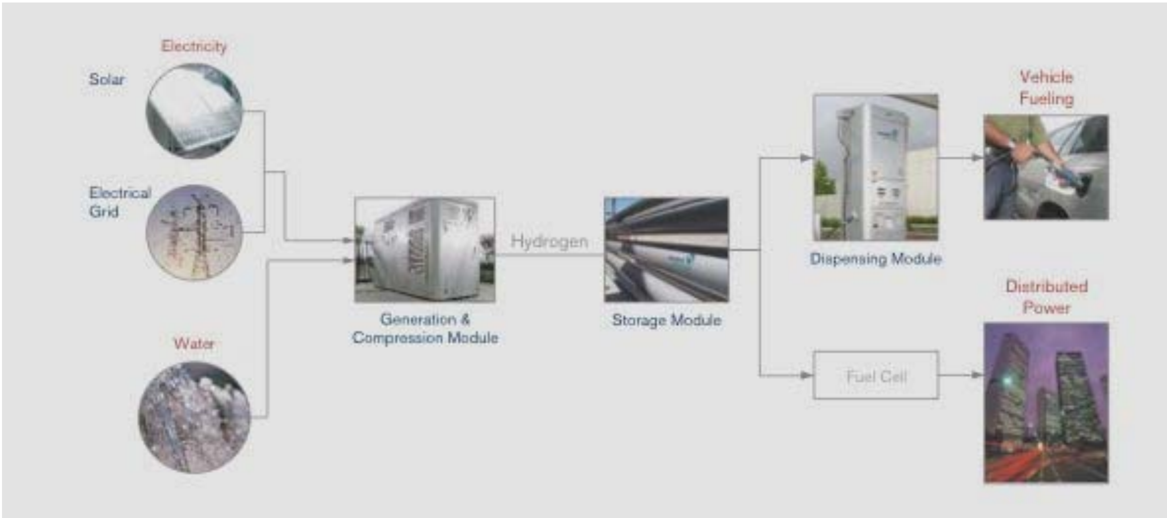
The American Honda Motor Company provides an example of the first solar-powered hydrogen production and fueling station. This is located in Torrance, California. It uses solar cells and has an electrolysis unit employing a high-efficiency ruthenium-based catalyst.

Source: American Honda Motor Company

First Solar-powered hydrogen production and fueling station
Torrance, California

An example in large-scale renewable hydrogen planning is the development of a 4000 MW wind farm on 350 square miles in North Dakota to produce hydrogen, to be delivered directly hundreds of miles away to Chicago via High Voltage Direct Current (HVDC) electricity lines or through a hydrogen pipeline.

Another hydrogen demonstration park opened in Michigan in October 2004. As illustrated below, the project uses renewable energy and electrolysis to produce hydrogen. The system runs during the evening, taking advantage of off-peak power prices to produce and store hydrogen. This hydrogen is then used in fuel cells to produce electricity during high-value peak periods, or is used as a zero-emission fuel for hydrogen-powered vehicles.



Hydrogen Demonstration Park, Michigan 2004

Canada

Canada is recognized as a centre of expertise in fuel cell research and development and early-stage commercialization. For over 20 years, the government of Canada has played an important role in the development of Canada's hydrogen and fuel cell industry. This is occurring at both the federal and provincial levels, as follows:

Federal Level:
- Investment by the Government of Canada of over $200M in this sector since the early 1980s;
- Forecasted investment of approximately $70M per year for over the next five years;
- Development of a national, coordinated strategy and implementation of key actions; and
- Creation of the Federal Hydrogen and Fuel Cell Committee (H2FCC).

Provincial Level:
- British Columbia continues to support large, integrated demonstration projects and is developing a hydrogen strategy;
- Alberta is developing hydrogen production strategy;
- Manitoba's hydrogen strategy is in the implementation stage;
- Ontario developing a strategy and supporting significant demonstration and deployment activities; and
- Prince Edward Island is focused on integrating renewable energy sources with hydrogen and fuel cell activities.

Canada has several major hydrogen projects underway. The Hydrogen Highway™ represents a hydrogen fueling infrastructure project demonstrating a wide variety of fuel cell applications, and will provide a global showcase at the 2010 Olympic Games in Whistler, British Columbia

The Hydrogen Village is a public-private partnership committed to accelerating and sustaining the application and commercialization of hydrogen and fuel cell technologies. Over 36 public and private sector members are contributing to the 2004 launch of the first Hydrogen Village for the Greater Toronto Area. Canada also has a number of international and bilateral hydrogen agreements. These activities are mainly focused on commercialization, breakthrough research, and transition technologies.

Canadian Industry Activities

One Canadian partnership of particular note is the Technology Partnerships Canada H2 Early Adopters Program. This program has funding of $50M over five years. This partnership with industry aims to foster the early adoption of H2 technologies and plans to:

- Demonstrate microcosms of the hydrogen economy such as the “hydrogen highways” and “hydrogen villages”;
- Develop H2 Infrastructure, codes and standards, skilled resources and an integrated supply chain; and
- Accelerate acceptance of hydrogen technologies.

Brazil

Brazil’s vision is to foster self-sustainable, environmentally-friendly and equitable projects. To achieve this vision, Brazil has been involved in hydrogen research for over two decades, and is building on this foundation.

HYDROGEN R&D IN BRAZIL: 1980 - 2003

		SOME INSTITUTIONS DEVELOPING TECHNOLOGICAL AND RESEARCH PROJECTS																					
		INSTITUTIONS																					
NET	AREA	Rede 10/01: N/NE	Rede 11/09: N/NE	UFBA	UFRJ	FUJB/MA	UFPR	USP/Ribeirão Preto	USP/São Carlos	UFSCAR/São Carlos	UNITECH	IPEN	UFMG/CDTN/CETEC	UNESP/Bauru	ELECTROCEL	COPPE/UFRJ	INT e INT/UFF	LACTEC	UEM	CEPEL	UNICAMP	CLAMPER	CENPES/PETROBRAS
Electro-chemistry	Solid Oxide	X		X	X				X	X		X	X	X	X	X							
	PEM, electrodes and membranes	X			X	X	X	X	X	X	X	X		X		X		X			X	X	
	Fuel Cells	X							X		X		X	X	X	X						X	
Reform	Natural Gas	X	X	X	X					X						X	X						X
	Ethanol											X	X				X		X		X		
	System engineering		X		X		X									X							X
Systems	System analysis						X									X		X		X	X	X	
	H_2 generation (electrolysis)								X												X	X	
	H_2 Storage							X								X					X		
	Safety, Codes and Standards																	X					X
	Integration										X							X		X	X	X	

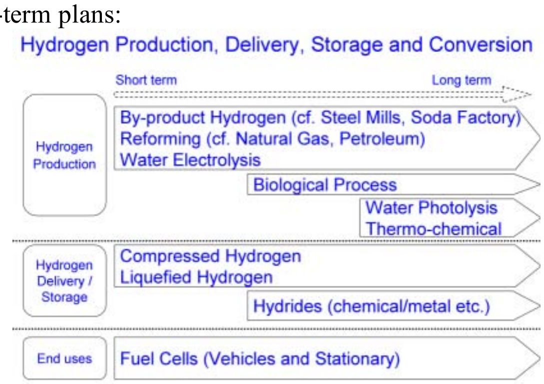
Brazil's renewable efforts include biomass reforming or gasification and hydro, solar and wind energy-driven electrolysis. Brazil is also targeting the following application of hydrogen technologies: remote and off-grid systems; heavy- duty transportation (urban buses and fleet vehicles); renewable energy storage systems; high quality, decentralized power generation; and hybrid and cogeneration systems (heat/power).

Brazil will be continuing to pursue technological developments; develop public policies; foster private investments; develop public education and outreach; increase public and private funding for technology development; public demonstrations and infrastructure development; and develop safety and performance codes and standards.

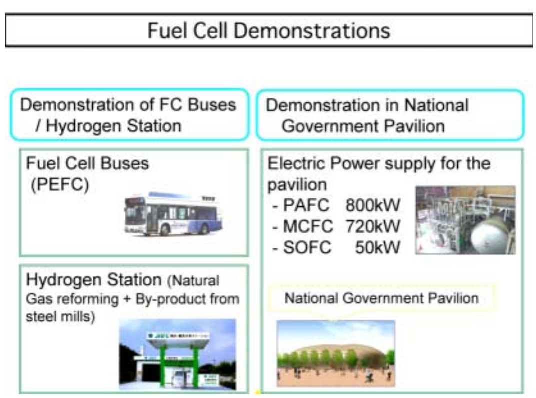
North Asia: Japan, Korea and China

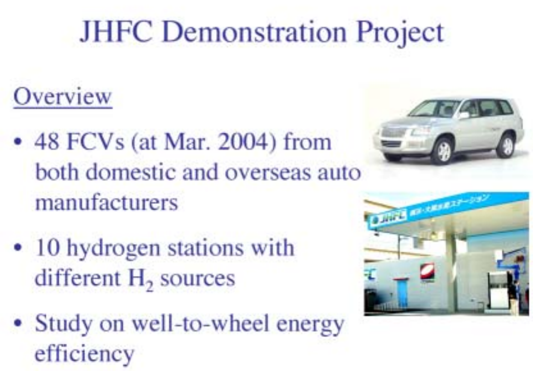
Japan

Japan's hydrogen and fuel cell programs are making use of multiple fuels, as noted below in the schematic below of short-term to long-term plans:



Japan is undertaking one of the most ambitious and comprehensive hydrogen initiatives in the world, with plans to spend $4 billion and have 5M fuel cell vehicles on the road by 2020.





On the renewable hydrogen path, the Environment Ministry also has decided to begin developing a system to extract hydrogen from seawater to power fuel cells, with the aim of creating a fully renewable energy supply. The envisioned system is to extract hydrogen from seawater through electrolysis using wind-generated electricity. A power station is to be built on a large floating structure in the ocean, where winds are relatively strong.

Korea

Korea plans to increase the portion of alternative energy in national energy consumption from 1.4% in 2002 to 5% by 2011; to select hydrogen and fuel cells as one of ten economic growth engines for the next decade; and to provide strong support for R&D on hydrogen and fuel cells. Some of the main areas of effort are the R&D for production, storage and usage; development and demonstration of hydrogen stations; high pressure vessels for hydrogen storage; and examination of safety codes and standards.

Korea is also planning the development of the following fuel cell systems;

- 100 kW class MCFC for stationary application;
- 80kW Class PEMFC for transportation;
- 3kW PEMFC for residential power generation;
- 50W class PEMFC, DMFC for portable application; and
- 3kW SOFC for auxiliary power units (APU) application.

The government has already earmarked $45 billion won ($38million) in a supplementary budget to expand greener energy projects such as co-generation.

China

China's concept of a hydrogen economy is one that is based on the following principles: diversified and domestically available hydrogen sources; production processes with the elimination of contaminants and the sequestration of carbon dioxide sequestration, if necessary; and mitigation of concerns about energy security, air pollution, climate change and dwindling non renewable energy resources.

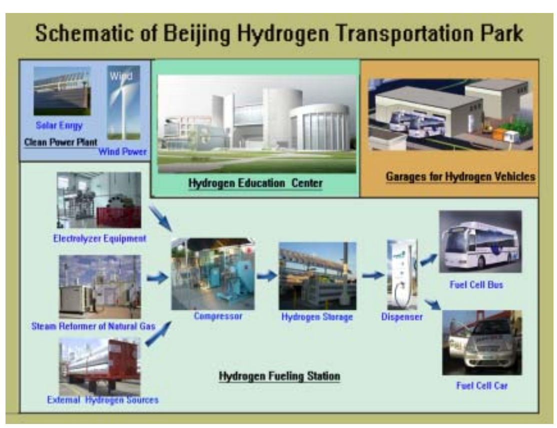
The national basic research program has 973 projects dealing with:

- Large-scale production, storage and transportation of hydrogen and associated fuel cells; and
- Smaller-scale hydrogen production using solar energy.

The national high-technology development program has 863 projects addressing:

- Post-fossil fuel hydrogen technology;
- Post-fossil high-temperature fuel cell technology;
- Clean coal technology and innovative hydrogen production; and
- Electric automobile technologies.

China's fuel cell vehicle program includes development of light-duty buses, mini-vans and cars. China also is working in collaboration with the U.S. and others on several fuel cell projects for the 2008 Olympics:



South Pacific: Australia and New Zealand

Australia

The Australian Government recognizes the potential of hydrogen to deliver significant economic and environmental benefits, and to reduce dependence on imported fossil fuels, thereby contributing to increased energy security. For these reasons, the Australian Government has committed significant resources in recent years to investigating the potential benefits of hydrogen in Australia's long-term energy supply. This work started with a specially commissioned national hydrogen study, completed in September 2003. It has been well-received by the various stakeholder groups in Australia.

The study's findings and recommendations are currently being considered by the Australian Government, in the context of a national energy policy. The direction-setting nature of the study and its recommendations mean that they are relevant not just to Australia. The recommendations support participation in international forums, such as IPHE, and continued active involvement in international research and industrial collaboration initiatives. The findings and recommendations also underscore the importance of Australia working with other nations and jurisdictions to remove or reduce policies and regulations that represent barriers to a transition to a future hydrogen economy. With the study completed, Australia is in the process of doing a detailed national stock-take of capabilities in hydrogen – in research, in technology and in industry, and in government.

Internationally, energy policy has moved centre-stage in recent years because of mounting concern over energy security, climate change and the need for greater attention to sustainability in resource use. In Australia, an Energy Policy Task Force was formed early in 2003 to work systematically through a broad range of issues that bear on energy resource development and use. The policy development work of the Task Force will take in recent actions that are relevant to Australia's progress towards a future hydrogen economy. In addition, Australia is an active participant in international fora across a range of energy sectors.

The Commonwealth Scientific and Industrial Research Organization (CSIRO), one of Australia's leading publicly-funded research bodies, launched its *Energy Transformed* initiative in October 2003. The research that will be undertaken through this initiative aims to develop technologies that will produce near-zero emissions power from fossil fuels. Other new CSIRO projects under this initiative involve solar-reforming of natural gas; direct solar water-splitting; and advanced water electrolysis. In the longer-term, the research being undertaken through CSIRO and similar organizations around the world could lay the foundations for large-scale hydrogen generation, and the widespread application of hydrogen technology to the transport sector.

New Zealand

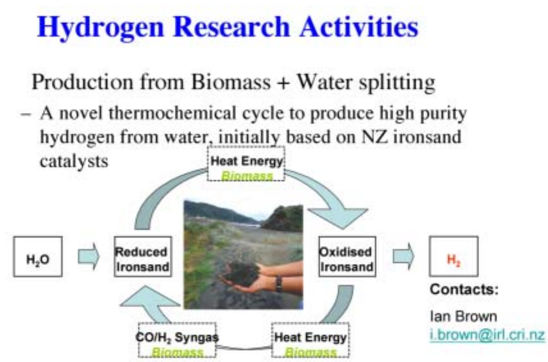
New Zealand has many renewable energy resources:

- Solar: very good, 1000 -1400 hours/year;
- Biomass: excellent growth rates, pinus radiata 20yr cycle;
- Wind: excellent, many sites > 45% capacity factor;
- Wave: excellent, (near-shore 20kW/m, deep-water 100kW/m); and
- Geothermal sites: additional sites for development exist.

New Zealand also has several government-funded hydrogen programs:

- Hydrogen Energy for New Zealand (2002-2008);
- Renewable Distributed Energy (2002-2008);
- Renewable Fuels for New Zealand (2002-04); and
- New Materials for the Hydrogen Economy (2004-06).

New Zealand also has ongoing research into hydrogen production from renewables, as noted below ,and storage using chemical hydride technologies. There are also a number of pilot fuel cell demonstrations.



South Asia: India and Pakistan

India

India is implementing renewable energy programs, an important step towards a renewable hydrogen future. India is very much a part of the globalization process, and seeks involvement in the global shift towards the hydrogen economy. India also views the harnessing of hydrogen energy as important for the developing world, which holds the great majority of poverty-stricken people across the globe. Access to commercial energy is not available to nearly two billion people, and their needs have to be kept in mind while mapping out the path of transition into the hydrogen era.

The road to overall global security lies in decreasing dependence on fossil fuels; and in making sure that all people have access to the energy they need to sustain life. The advent of this new economy is a promissory note for a safer world.

India has achieved progress on different aspects of the hydrogen system, including production and storage applications. In addition, prototype hydrogen vehicles, including motorcycles, three wheelers, fuel cell cars and vans, and hydrogen-powered generators, have been demonstrated India. In the next phase these applications, will be put on extensive field trials through partnerships with industry.

India has extensive renewable energy potential from solar, wind, hydro and biomass. As discussed recently at the World Renewable Energy Congress (WREC) 2004, India has only begun to tape into these resources.

Strong government-research-industry partnerships are necessary to develop hydrogen energy technologies for large-scale commercial use. This will also require good coordination among various government agencies, academic and research institutions, and industry.

Pakistan

A major objective for Pakistan is to achieve a 10% share in the country's electrical power generation by 2010 by providing energy through alternative resources. According to a new law that is going to be enforced soon, it will become mandatory for every new building and hotel to install solar-powered hot-water geysers. Also planned are projects focusing on power generation through windmills as well as hydrogen fuel cells as an alternative to pollution-emitting petrol or diesel generators. A wind-energy park is already functional in Rawalpindi, which lies just alongside Islamabad, and others are planned for Karachi.

About 100 homes in a small village near the capital, Islamabad, are to be supplied with solar power in the first of a series of endeavors to bring alternative or renewable energy resources into the national mainstream over the next decade. A mosque in Alipur Farash, a village nestling in the undulating countryside on the outskirts of Islamabad, had already been fitted with solar panels in a test run before at least 100 homes in the community were provided with the same equipment

Southeast Asia: Thailand, Malaysia, Singapore, Indonesia, and Philippines

The Association of Southeast Asian Nations (ASEAN) includes Brunei, Cambodia, Indonesia, Laos, Malaysia, Myanmar, Philippines, Singapore, Thailand, and Vietnam. http://www.aseansec.org/home.html Examples of ongoing renewable energy programs and related hydrogen activities are provided for Thailand, Malaysia, Singapore, and Indonesia.

Thailand

Thailand is generously endowed with renewable energy sources -- especially biomass, solar, and hydro energy , all of which are widely distributed across the country and can be utilized through commercially viable technologies to generate energy/power. (http://www.netmeter.org/en/energy_sources)

- Biogas -- Methane-rich biogas can be produced directly from livestock manure and wastewater from various food processing operations. The gas can be burned to produce heat or to fuel electricity generators.
- Biomass -- Thailand's considerable biomass resources include waste products from the rice, sugar, palm oil, and wood-related industries. An estimated 60 million tons of agricultural and wood residues are produced domestically each year.
- Solar PV -- Thailand has excellent solar resources, with the most intensive solar energy found in the north and central regions. There is presently about 5.5 MW of **Solar PV** installed in Thailand, mostly off-grid in remote areas. The government expects another 9 MW of grid-connected PV will be installed by 2006.
- Micro-Hydro -- Since 1983, 59 **micro-hydro** power generators, sized under 200 kW each, have been installed in rural Thai communities. Although only half of this 2 MW of installed capacity remains in service, net metering now allows these systems to connect to the grid to generate electricity and income.
- Wind -- Thailand's best **wind** potential is found along the eastern coastline of the southern part of the Gulf of Thailand, and in the mountains of the west and southern regions. The government hopes to reach 3-6 MW of installed wind capacity by 2006.

Indonesia

Indonesia is a large oil and natural gas producing country and almost 77% of its energy needs are met through fossil fuel combustion. However, economic crisis, depletion of oil reserves and environmental concerns are accelerating Indonesia’s movement towards greater use of renewable energy resources.

The World Bank has contributed to several large-scale renewable energy projects, including the "Solar Home System" project that aims to electrify remote areas through renewable energy. Solar/PV technology is an attractive option in Indonesia because the country is fragmented among numerous small islands, making a comprehensive grid difficult to construct.

Indonesia possesses significant hydroelectric potential, but has done little to exploit it. There is a government-built, 5,600-MW hydropower plant in Irian Jaya that supports economic development. Java also has several hydropower facilities with combined installed capacity is 2,550 MW.

Indonesia has significant geothermal energy potential. The "Ring of Fire," the world's most active volcanic zone, stretches along the southern coast of the islands of Sumatra and Java. Use of geothermal resources remains highly tentative, however. According to a February 2002 report by the U.S. Embassy in Jakarta, Indonesia had developed 787 MW of geothermal capacity. This represented only 4% of its estimated geothermal potential of 20,000 MW. About 40% of this potential is located in Java and Bali, the two most populous islands in the Indonesian archipelago.(http://www.eia.doe.gov/emeu/cabs/indonesa.html).

Malaysia

Malaysia has substantial oil and gas resources but also is investing in development of renewable hydrogen. A National Steering Committee on Hydrogen Energy, Solar Energy and Fuel Cells has been established at the Malaysian Ministry of Energy, Communication and Water. The Steering Committee is conducting the Malaysian Road Map on Hydrogen Energy, Solar Energy and Fuel Cells. There already are a number of projects at the Universiti Kebangsaan Malaysia and the Universiti Teknologi Malaysia dealing with fuel cell developments, PV-electrolyzers, photoelectrolyzers, and storage systems. Several designs are being tested and a number of facilities have been set up for the active research programs.

Malaysia's Eco-House, undertaken to explore the solar/hydrogen technology as a viable source of energy for residential development, is another example of the efforts in renewable hydrogen. The house is an ambitious Solar-Hydrogen powered home sited at the University Kebangsaan Malaysia in Bangi, Malaysia. This house utilizes a PV electricity production and storage system in conjunction with Proton's HOGEN RE hydrogen generator and a fuel cell to capture, store, and regenerate the electricity necessary to power household appliances.
(http://www.fuelcelltoday.com/FuelCellToday/IndustryInformation/IndustryInformationExternal/NewsDisplayArticle/0%2C1602%2C4530%2C00.html).

Singapore

Oil and gas reserves are the major source of energy for Singagore. However, the country has committed to two significant renewable energy targets: installation of 50,000 square meters of solar thermal systems by 2012; and complete recovery of energy from municipal waste.

The country also has several renewable energy policies and measures, including tax incentives for energy-efficient equipment; innovation for environmental sustainability; and environmental test-bedding initiative; and joint research with tertiary institutions. (http://www.iea.org/dbtw-wpd/textbase/pamsdb/jrcountry.aspx?country=Singapore)

Philippines

To address its looming power shortages and the current need to import fossil fuels, The Philippines has an aggressive program to develop and use indigenous, renewable fuels. The U,S.-Philippines cooperation is helping implement the landmark 2001 Electric Power Industry Reform Act (EPIRA). The Energy Plan has as its renewable energy targets the following:

- To double renewable energy-based capacity by 2013
- To become the largest geothermal energy producer in the world
- To be the leading wind energy producer in Southeast Asia
- To double hydro capacity by 2010
- To install 130-250 MW of biomass, solar and ocean energy capacity
- To become the solar manufacturing export hub of the ASEAN region

In addition to a plan calling for energy self-sufficiency by 2013, the plan also calls for 100% electrification of barangays by 2006, promotion of clean fuels, and continued international cooperation. This strong renewable energy plan and a diverse, renewable portfolio is an excellent starting point for the development of a hydrogen economy.
(http://www.doe.gov.ph/servlet/page?_pageid=2778&_dad=portal30&_schema=PORTAL30)

Near East: Egypt

In 1986, the New & Renewable Energy Authority (NREA) was established to provide the institutional framework for implementing renewable energy strategies and to act as a national focal point to introduce renewable technologies to Egypt on a commercial scale. The Ministry of Electricity and Energy (MEE) has formulated a strategy aimed at having renewable energy sources satisfy 3% of the Egyptian electrical energy demand, mainly from wind and solar by 2010, and 7% by 2020. Resource assessments for wind and solar have been conducted. The first 5.5 MW wind farm has been established and is interconnected with the grid. Several smaller operations also are in place. The first hybrid solar/fossil thermal power plant is under implementation as well. Egypt also has a pilot project on solar industrial process heat and domestic solar water heating demonstrations, Applications in PV such as water pumping, desalination, clinical refrigerators, and village electrification have been field tested. Other PV applications in telecommunication systems have already been commercialized. The Centre of Testing & Certification is entrusted to carry out tests on performance, reliability, and durability as well as environmental effects of renewable energy equipment.

Summary—International Renewable Hydrogen Experience

The renewable hydrogen economy vision, as illustrated below, is realistic and is beginning to be realized in different ways in many countries.

As illustrated by the country examples above, key ingredients for attaining success in the renewable hydrogen economy are a combination of:

- Good renewable energy resources, of one kind or another, that allow a country to achieve total energy independence and energy security;
- Use of these resources in developing enough economically-viable electricity and hydrogen;
- Recognition of the multiple environmental and societal benefits of using renewable energy;
- Support of national policies that help make the economics more favorable to renewable hydrogen;
- A well-informed public that not only encourages government to support renewable hydrogen but also guarantees use of renewable hydrogen products and services; and
- International cooperation on renewable hydrogen research, development and deployment that encourages local development as well as advances in other countries.

Towards a Secure and Renewable Hydrogen Future for Asia – Possible Pathways Forward

The ingredients for joining a renewable hydrogen economy include, first and foremost, the availability of renewable resources. Resource assessment quantifies information on resources, and helps accelerate development and deployment of technologies. This analytical, important first step is described below, and examples of available resource assessments from Asia are used to illustrate the process and the results.

Translating available resources into useful energy supply depends on a number of factors, including the following: land use issues (e.g., is the land where resources are high being used for a competing purpose like farming); economics (e.g., do new transmission lines need to be developed to carry the resource to the grid, is there a way to pay for the capital and operation costs of using the resource); and politics (e.g., will existing utilities allow access to the grid, is there net metering). These factors also need to be considered in the resource assessment process.

Ability to effectively use renewable resources to produce electricity and hydrogen, political will, and cooperation all are key essential ingredients. Assessing the status of these ingredients throughout Asia helps clarify possible pathways forward for individual countries, and for the region as a whole.

During the workshop, the participants will discuss key ingredients and possible next steps. These discussions, along with individual country presentations, will be synthesized into a post-workshop planning document as a contribution to the regional planning processes.

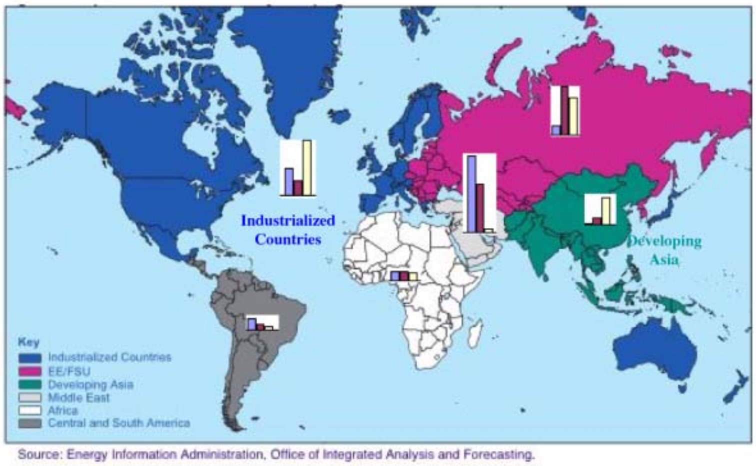
Excellent Renewable Energy Resources in the Asia / Pacific Region

The Asia / Pacific has a wealth of renewable energy resources, and many areas have more than one excellent resource. This means that this region has a very promising renewable hydrogen future.

Renewable Energy Supplies Needed to Meet Energy Demands

Excellent renewable energy resources are very important assets, since Asia has the highest projected energy demand and among the lowest proven fossil fuel reserves in the world. In the figures below the energy demand for 1990 and 2025 and the estimated fossil fuel reserves are compared to those for the rest of the world (International Energy Outlook 2003 www.eia.doe.gov/oiaf/ieo/index.html.)

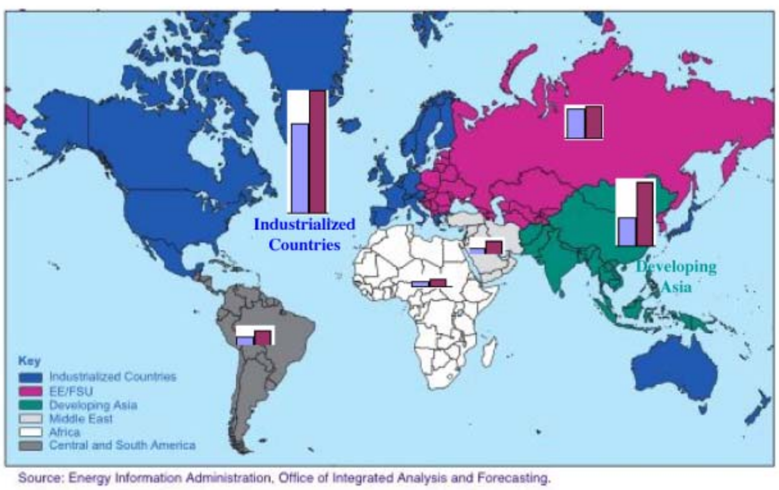
ASIA / PACIFIC SUPPLY and DEMAND GAP



Fossil Fuel Reserves -- % of World Total Estimates

Oil Natural Gas Coal

Low Supplies of Reserves (Particularly Oil) for Developing Asia



Energy Demand Changes 1990 To 2025

Highest Increasing Demand Projected for Developing Asia

Resource Assessment

Resource assessment is the process of developing information on the availability of energy resources for renewable energy technology applications. Information on quality, as a function of location and time, are presented in maps, charts and tables. Good resource data helps to ensure that projects meet economic goals, systems are properly designed and projects stay on schedule.

Techniques for assessing resources make use of a unique integration of global terrain and climatic data sets, satellite-derived data, Geographic Information Systems (GIS) technology, and analytical and computational techniques, many of which have been developed and refined by U.S. Department of Energy National Renewable Energy Lab (NREL) and its collaborators over many years. (e.g., http://rredc.nrel.gov/). The global data sets and analytical tools permit modeling and resource predictions that do not need to rely on country-supplied data. However, any high-quality data that can be obtained from a specific country can be used to enhance the modeling process, as well as for validation of the resulting maps.

Excellent Grade Geothermal Energy Resources in Asia

Geothermal reservoirs that are close enough to the surface to be reached by drilling can occur in places where geologic processes have allowed magma to rise up through the crust, near to the surface, or where it flows out as lava. The crust of the Earth is made up of huge plates, which are in constant but very slow motion relative to one another. Magma can reach near the surface, where Earth's large oceanic and crustal plates collide, and one plate slides beneath another.

The best example of these hot regions around plate margins is the "Ring of Fire", which includes Japan, the Philippines, Indonesia and New Zealand. They also occur where the plates are sliding apart, such as Iceland, and places called "hot spots"-- fixed points in the mantle that continually produce magma that comes to the surface. Because the plate is continually moving across the hot spot, strings of volcanoes are formed, such as the chain of Hawaiian Islands. Geothermal energy resources throughout the world are illustrated by the locations of the high temperature geothermal provinces (areas circled by red in the figure below). A number of regions in Asia are excellent candidates for geothermal energy. (World Energy Council http://www.worldenergy.org/wec-geis/publications/reports/ser/geo/geo.asp)

Global Geothermal Resources

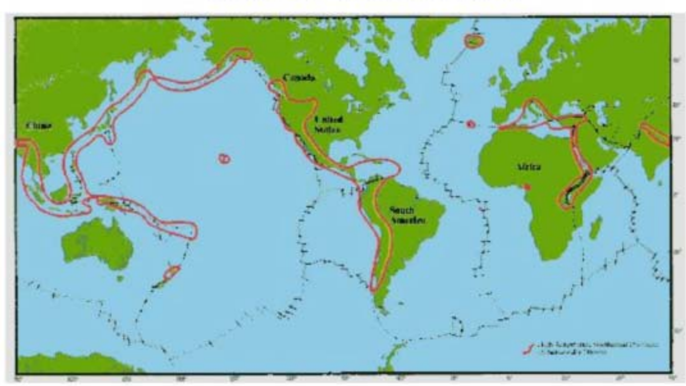


Figure 12.5: World High Temperature Geothermal Provinces
(Source: *Geothermal Energy*, 1998, University of Utah)

Geothermal resource potential for a particular area is determined by the following: defining the critical parameters for economically significant resources of geothermal energy; compiling literature and canvassing geothermal experts worldwide; and creating a map of both known and inferred geothermal resources indicated by such parameters. Parameters include heat flow, volcanic, and hot spring data. Resource estimates are based on heat flow rates, which are determined by multiplying the thermal gradient in ^{0}K/m and the thermal conductivity in W/m-^{0}K. Those areas designated as having electric generation potential show heat flow rates ranging from 80 to 151 mW/m^2. Areas designated with having direct use potential show heat flow rates ranging from 60 to 80 mW/m^2. Areas with heat flow rates less than 60 mW/m^2 are considered appropriate only for ground-source heat pump applications.

The electricity generation resource potential for geothermal in Asia is substantial and the resources already are being used in many places. Examples for the Asia / Pacific region are indicated by area 2-7 below.

2. Japan - The best known example of a volcanic country on the Pacific "ring of fire," Japan, has been volcanically active over the past 20 million years.

3. Eastern China- Eastern China is not close to a plate boundary, but has hot water in sedimentary basins similar to those in northern Europe.

4. Himalayan Geothermal Belt - The collision of the Indian plate with the Eurasian plate resulted in the Himalayas and one of the largest geothermal areas in the world. The Himalayan geothermal belt, over 150 km wide, extends 3000 km through parts of India, Tibet, Yunnan (China), Myanmar and Thailand. Over 150 of the hot spring areas are hot enough to generate electricity.

5. The Philippines- These islands have remarkable geothermal resources. Rapid subduction of the Philippine plate under the Eurasian plate results in active faulting and volcanism. Philippine geothermal fields are substantial.

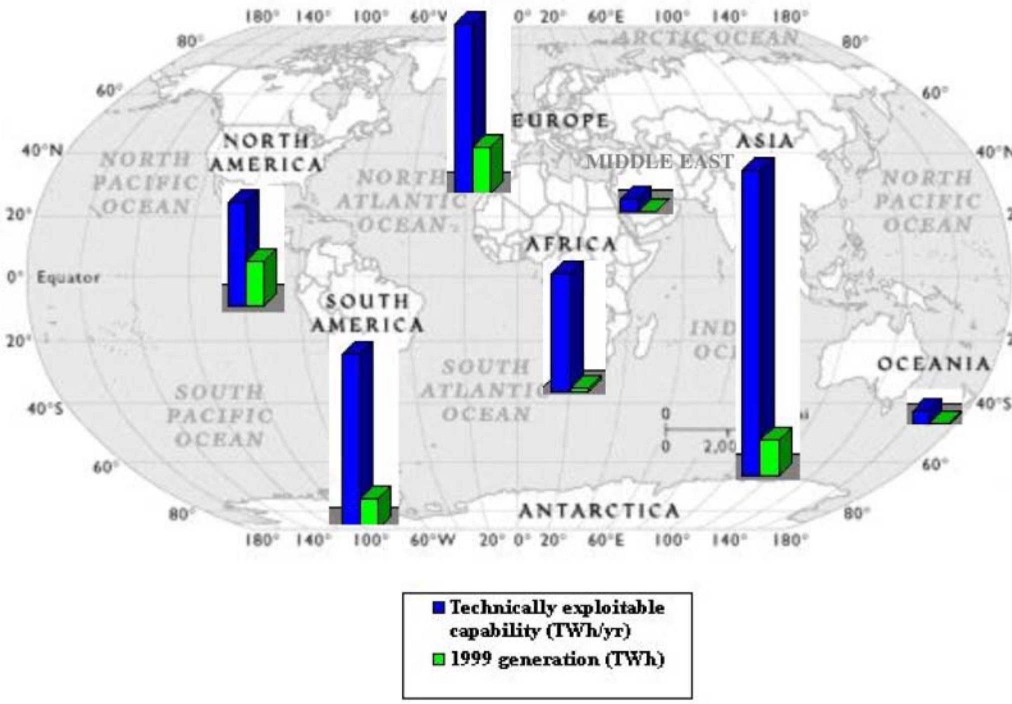
6. Indonesia - In the Indonesian islands, a great subduction plate boundary 4000 km long between the Eurasian and Australian plates has formed nearly 200 volcanoes and 100 geothermal fields.

7. New Zealand - This country, along the southeast subducting boundary of the Pacific plate, has many hot-spring areas and several active volcanoes.

Excellent Grade Hydropower Resources in Asia

Flowing water creates energy that can be captured and turned into electricity. This is called hydroelectric power or hydropower. The most common type of hydroelectric power plant uses a dam on a river to store water in a reservoir. Water released from the reservoir flows through a turbine, spinning it, which in turn activates a generator to produce electricity. Hydroelectric power does not necessarily require a large dam. Some hydroelectric power plants just use a small canal to channel the river water through a turbine. A small or micro-hydroelectric power system can produce enough electricity for a home, farm, or ranch.

As noted below, for Asia the hydropower capacity is very high relative to other parts of the world, and most of these resources have yet to be harnessed. (World Energy Council http://www.worldenergy.org/wec-geis/publications/reports/ser/hydro/hydro.asp)



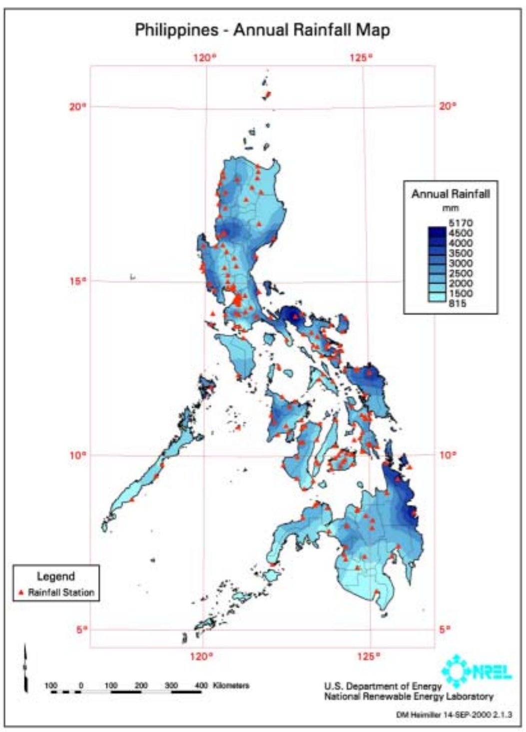
Hydropower--Technically Exploitable Capability and 1999 Generation (all schemes)

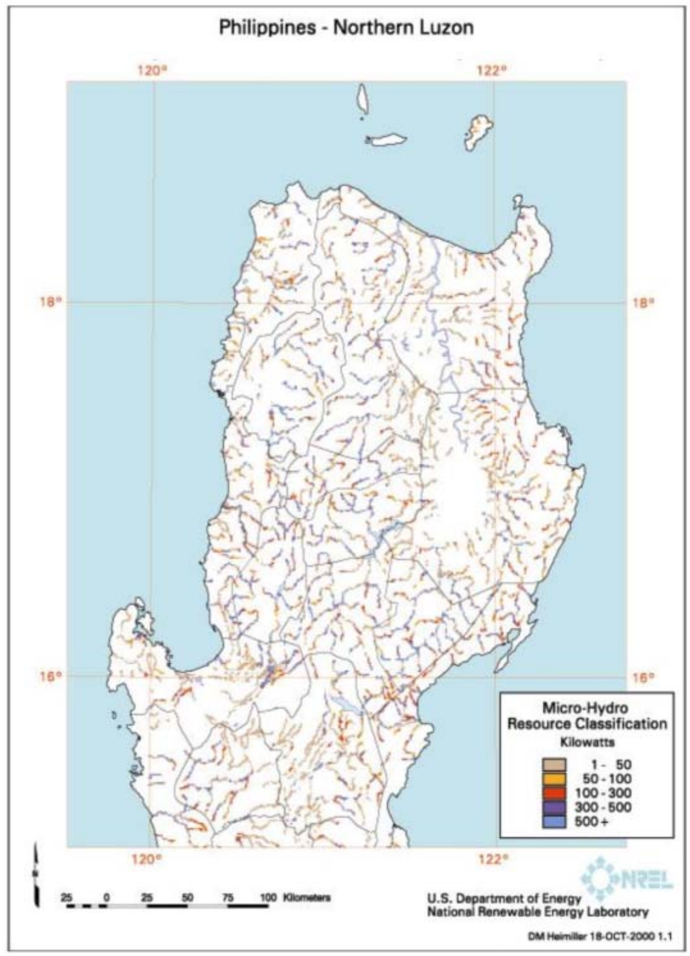
Countries of mainland s Southeast Asia (Thailand, Cambodia, Laos, Myanmar, and Vietnam) have high hydropower potential, as they are drained by five major river systems: the Irrawady, Salween, Chao Phraya, Mekong, and Red River. Except for Vietnam, countries of mainland Southeast Asia only have aggregate estimates of hydropower potential—potential undivided among the different scales of hydro technology. Though separated by seas and not having common major river systems, the countries of insular southeast Asia—Indonesia, Malaysia, Brunei and Philippines—also have high potential for hydropower. (http://www.asem-greenippnetwork.net/dsp_page.cfm?view=page&select=132)
Hydro is also an excellent resource in Nepal, India and Sri Lanka.

Micro-hydro development is attractive since the systems can be set up and operated much more economically and faster than larger scale projects, making them particularly appealing for rural electrification projects. For example, a recent micro-hydro assessment for the Philippines was carried out to facilitate Barangay electrification. (http://www.doe.gov.ph/servlet/page?_pageid=1062,1064,1066&_dad=portal30&_schema=PORTAL30)

The resource assessment for the Philippines provided below illustrates the high level of detail possible and also underscores the high quality resource available. Precipitation, an important determinant of hydro potential, is high throughout the Philippines. The Northern Luzon area has multiple waterways, with high-end micro-hydro potential.

Philippines
Hydro Potential





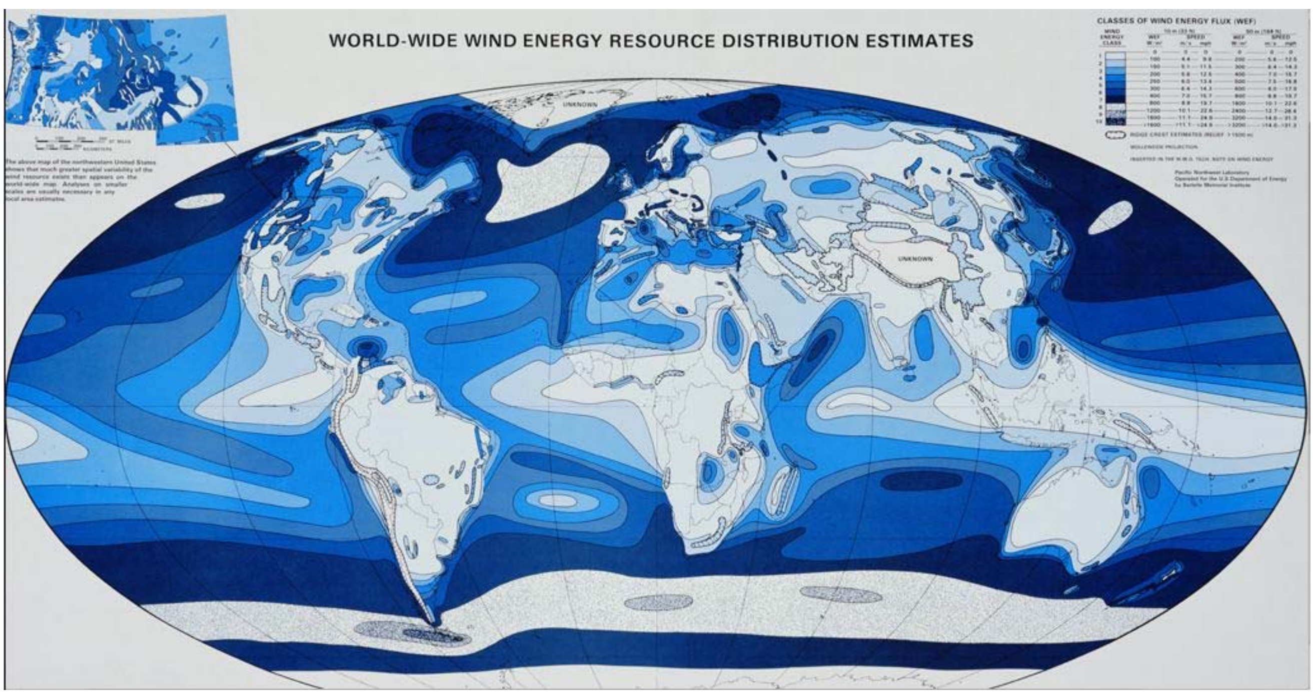
Excellent Grade Wind Energy Resources in Asia

Wind is created by uneven solar heating. The resource is widely distributed, and is used for small-scale rural power and water pumping, and for large-scale utility-connected bulk power.

Metrological wind speed data are important determinants of the resource, since power in the wind increases with the cube of the wind speed Wind speed generally increases with height above the ground, making it important to include both surface and upper air wind speed measurements in an assessment It is affected by large-scale weather patterns, geographic features like cliffs and mountains, and local obstructions like trees and buildings. Wind speed varies over time due to local turbulence, diurnal variability, seasonal variability, and inter-annual variability

In addition to the weather data (i.e., ground and upper air wind as a function of time), assessment of potential requires topographic and other information about the physical sites such as its proximity to transmission grids, roads and restricted areas (Wind Resource Assessment Handbook www.nrel.gov/docs/legosti/fy97/22223.pdf and National Wind Technology Center http://www.nrel.gov/wind/wind_pubs.html)

Wind resources can be found worldwide. An illustration of the global distribution of wind resources is provided by this early assessment map (improved global maps are under development). The darker shades of blue indicate higher resource levels.

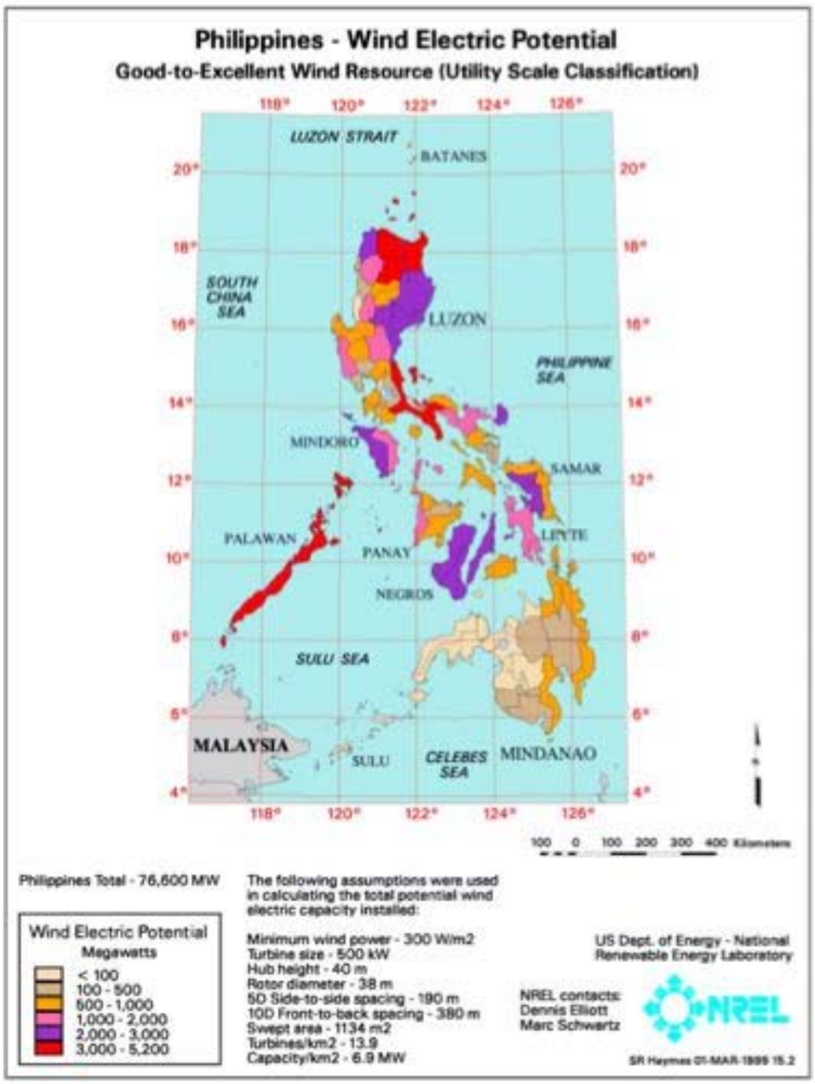


Considerable data is now available for developing detailed assessments of wind resources. For example, NREL's global meteorological data sets include nearly 30 years of land and ocean surface and upper air observations (with wind data), as well as 15 years of satellite-derived ocean wind data. There also are several global model-derived grid-based data sets, including a 40-year Reanalysis database of 2800 grid points, each with four vertical profiles of wind per day for 40 years. For regions of detailed wind mapping, high-resolution, gridded model output data can be generated by a mesoscale meteorological modeling system. These data provide the primary basis for the preliminary wind assessment of a region. NREL then applies its analytical and empirical approaches to validate and revise the preliminary estimates, as needed.

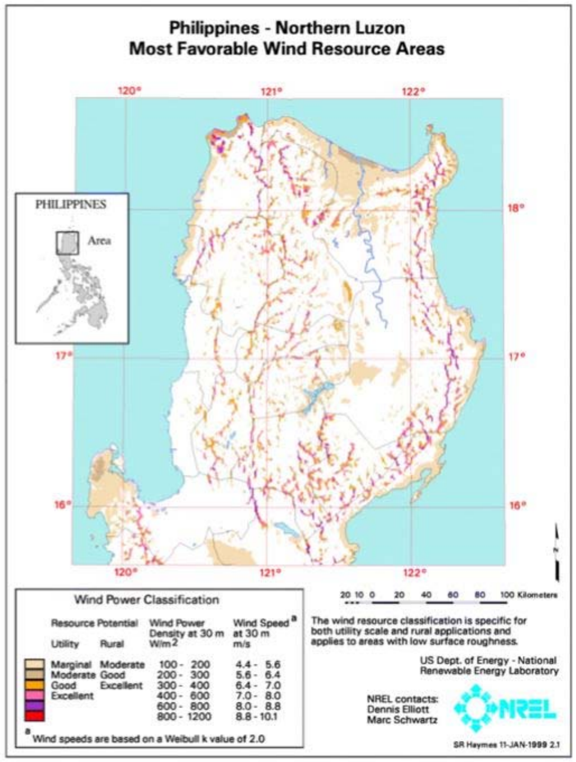
Additional products, helpful to determining how best to use the resource, such as geographic and terrain maps for use with the wind maps, and summaries of important wind resource characteristics, such as the seasonal, diurnal, and directional variability of the wind resource, also can be made available as part of an overall wind resource assessment.

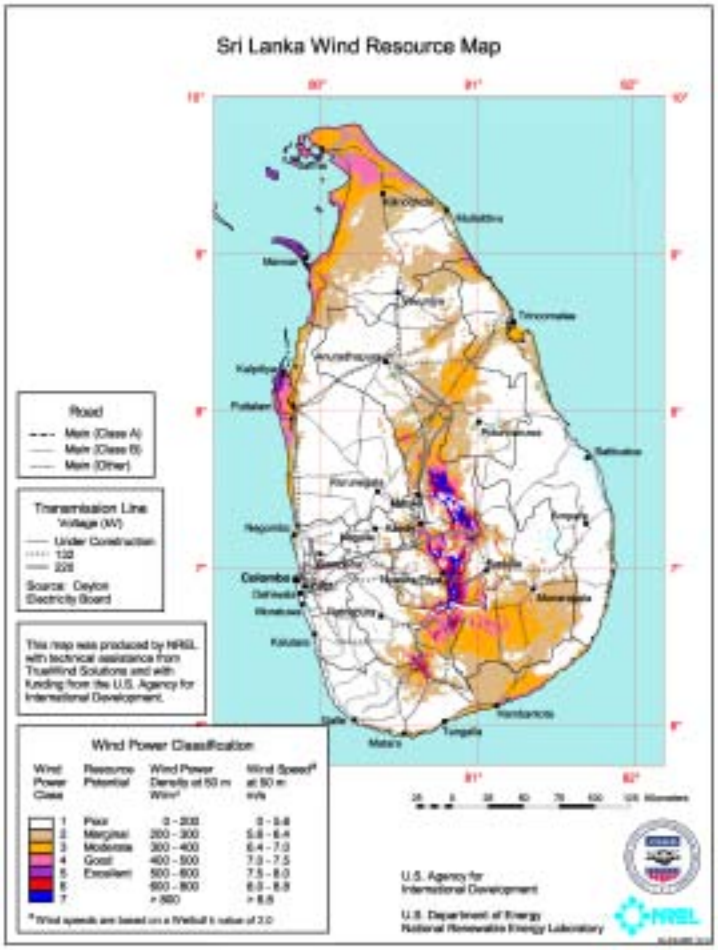
These much more detailed wind resource assessments, such as the ones presented below for the Philippines and Sri Lanka, indicate more precisely where the resources are best throughout individual countries (NREL http://www.rsvp.nrel.gov/wind_resources.html). As illustrated here, the resources are high in several areas in both countries.

The Philippines example illustrates the country assessment and a detailed examination of one particular region of the country with particularly promising resources. For the complete country assessment, the total potential wind electric capacity installed is estimated for different regions of the country. The highest estimated potential is shown in red.
A 2000 estimate of the total wind potential of the Philippines was 76 GW.



Further detailed assessment for northern Luzon, an area with particularly high wind electric potential, indicated that there are many locations with excellent resource potential for both utility and rural applications.





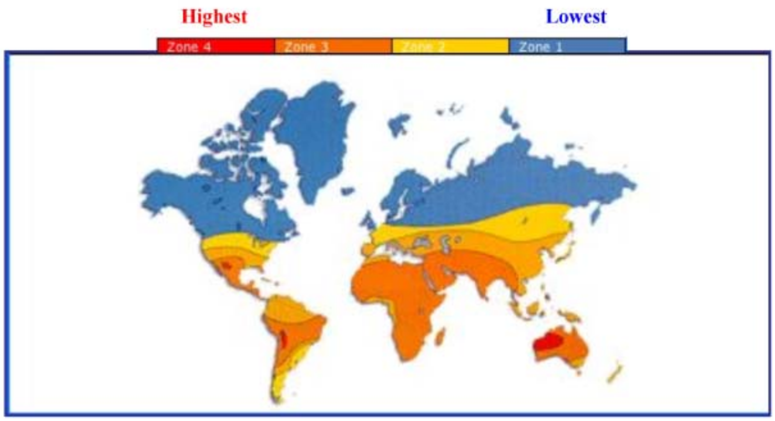
In the Sri Lanka examples, the wind power resource potential is rated excellent for many areas. For these analysis results, the map also includes important infrastructure information regarding roads and transmission lines, to further assist in decision-making regarding optimal locations for installations.

Excellent Grade Solar Energy Resources in Asia

Solar radiation is electromagnetic radiation from the sun, has strongest energy in the visible wavelengths, and is expressed in energy units per area (i.e.., kWh/m2, MJ/m2, BTU/m2). The amount of solar radiation available at a location is influenced by clouds, geography (i.e., mountains, oceans, large lakes), latitude and season, air pollution and natural haze, and volcanic activity. All of these factors need to be considered when doing an assessment.

As noted earlier in the report, and included here again, solar resources are ubiquitous throughout the world. Areas with some of the highest-quality resource are located in the Asia / Pacific region.

Global Solar Resources



Estimated Monthly Kilo watt-hours (kWh)
Produced by Grid-Tie System at
Roof Tilt on a 2400 Watts system
http://www.oksolar.com/technical/daiy_solar_radiation.html

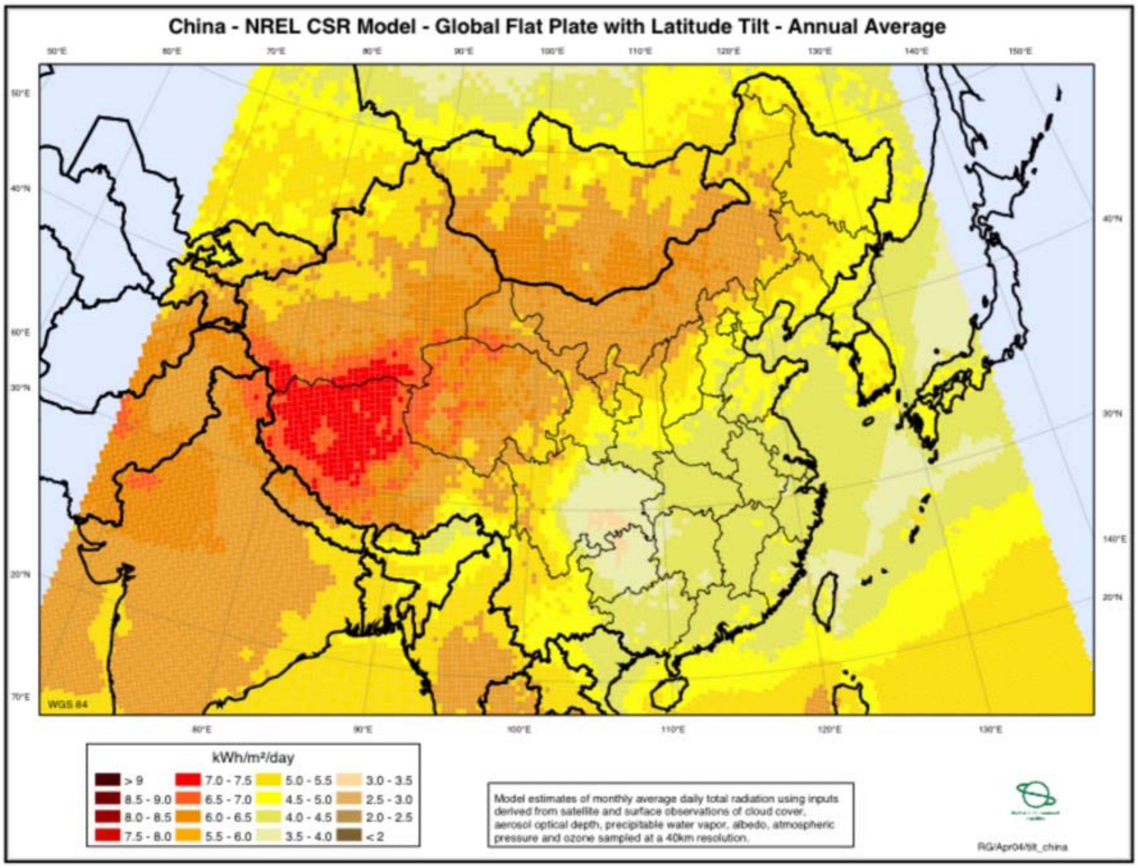
Assessments of solar resources using measurement practices, as well as modeling approaches such as those developed by NREL, provide detailed information that can be used to address the needs of all solar technologies. For example, data analysis can provide information on the resource received by flat plate collectors, such as photovoltaics, and concentrating collectors used in solar thermal systems. The data can also assist building designers in making better use of the solar resource for efficient daylighting and other building design considerations.

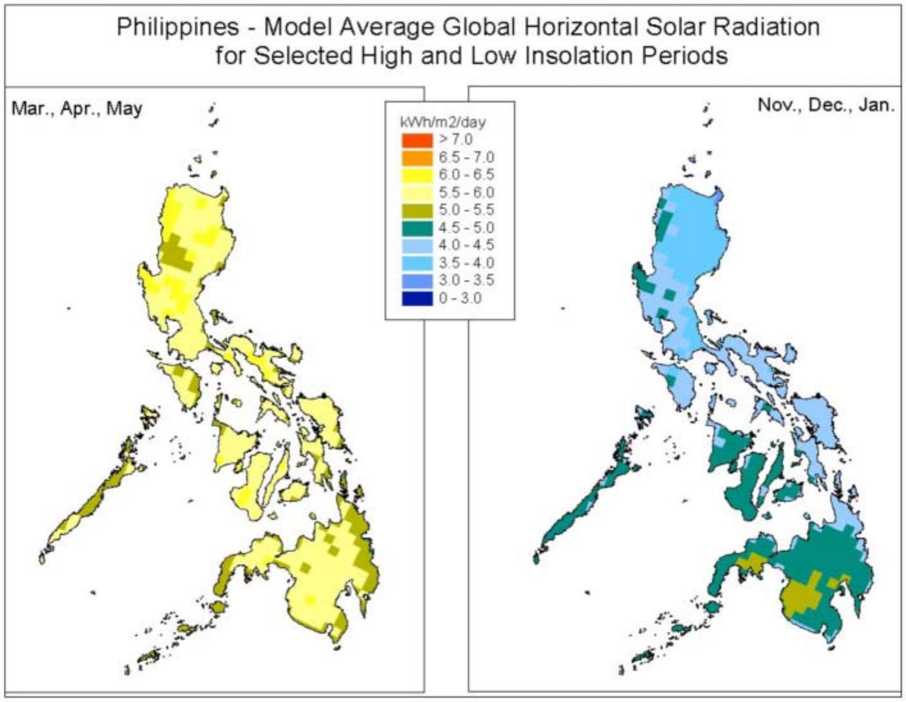
Several modeling approaches have been developed to improve the spatial coverage of solar resource estimates where actual measurements are lacking, or to supplement measurement networks. The basic approach used by NREL is to make use of satellite imagery, combined with solar radiation models, to develop large-area assessments of solar resources at high spatial resolution.

Applications of these techniques to determine the solar energy resources for several areas of Asia are illustrated below. As can be seen in the assessments, all areas have some level of resource and many have exceptional resources throughout the year (NREL http://rredc.nrel.gov/solar/#archived).

The map for China shows the annual average solar resources. The maps for the Philippines and Sri Lanka illustrate the differences for high and low insulation periods. This helps indicate seasonal differences in the resource. For both countries the resource is good in some parts of the country, even during the relatively low periods.

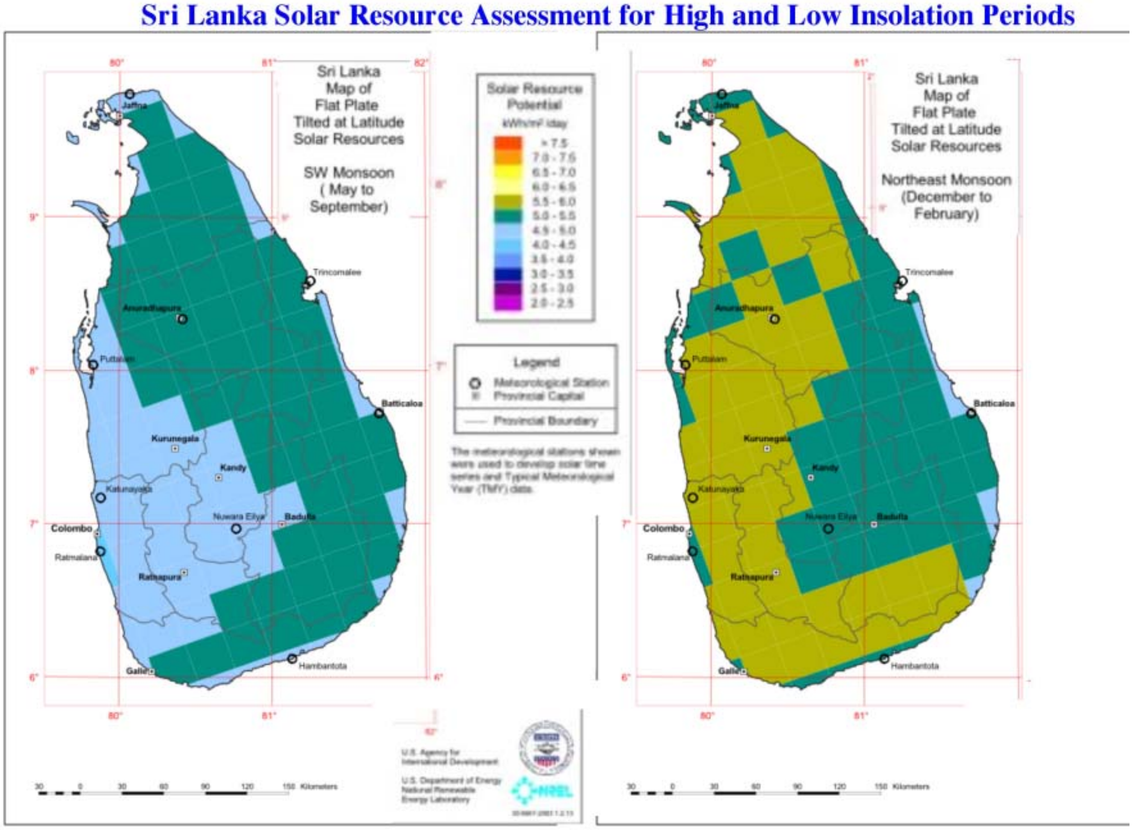
Annual Average Solar Resources in China : 40-km Resolution





For the Philippines the high insulation period is illustrated on the left and the low period on the right.
For Sri Lanka the high insulation period is illustrate on the right and the low period on the left.

Sri Lanka Solar Resource Assessment for High and Low Insolation Periods



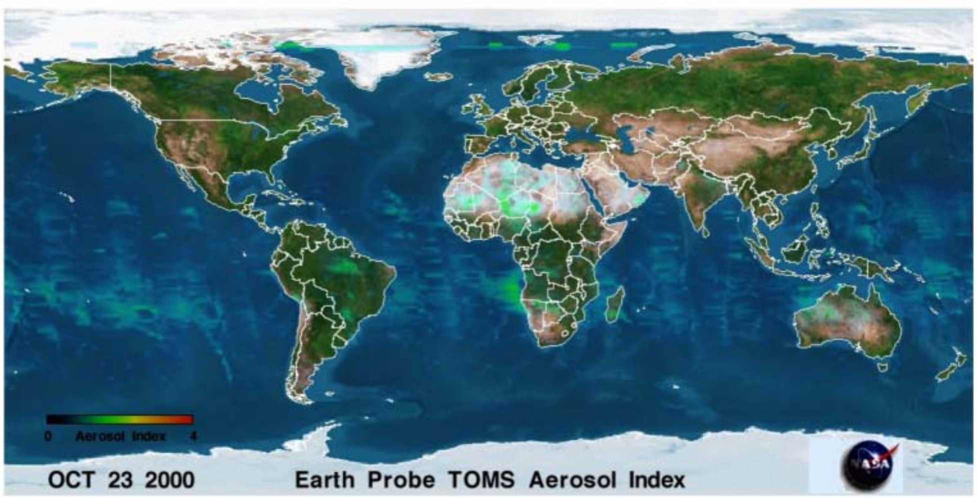
Excellent Biomass Energy Resources in Asia

Biomass energy is stored energy from the sun, contained in materials such as plant matter and animal waste, known as biomass. Biomass is considered renewable because it is replenished more quickly when compared to the millions of years required to replenish fossil fuels. The wide variety of biomass fuel sources includes agricultural residue, pulp/paper mill residue, urban wood waste, forest residue, energy crops, landfill methane, and animal waste.

Biomass is the fourth largest fuel currently in use for the world. It's potential is a function of land characteristics and competitions for other uses. For example, food, urbanization, water, conservation and fibre all compete for use of land. The potential also is influenced by utility operations and costs of biomass as a delivered energy form.

Biomass is particularly high (green areas) in many parts of the Asia / Pacific region, as is illustrated in this distribution of biomass obtained from satellite analyses. (NASA Earth Probe. Total Ozone Mapping Spectroradiometer (TOMS) http://toms.gsfc.nasa.gov/aerosols/aerosols_v8.html)

Biomass Distribution



There are basically four levels of survey and assessment for determining biomass resources in various levels of detail:

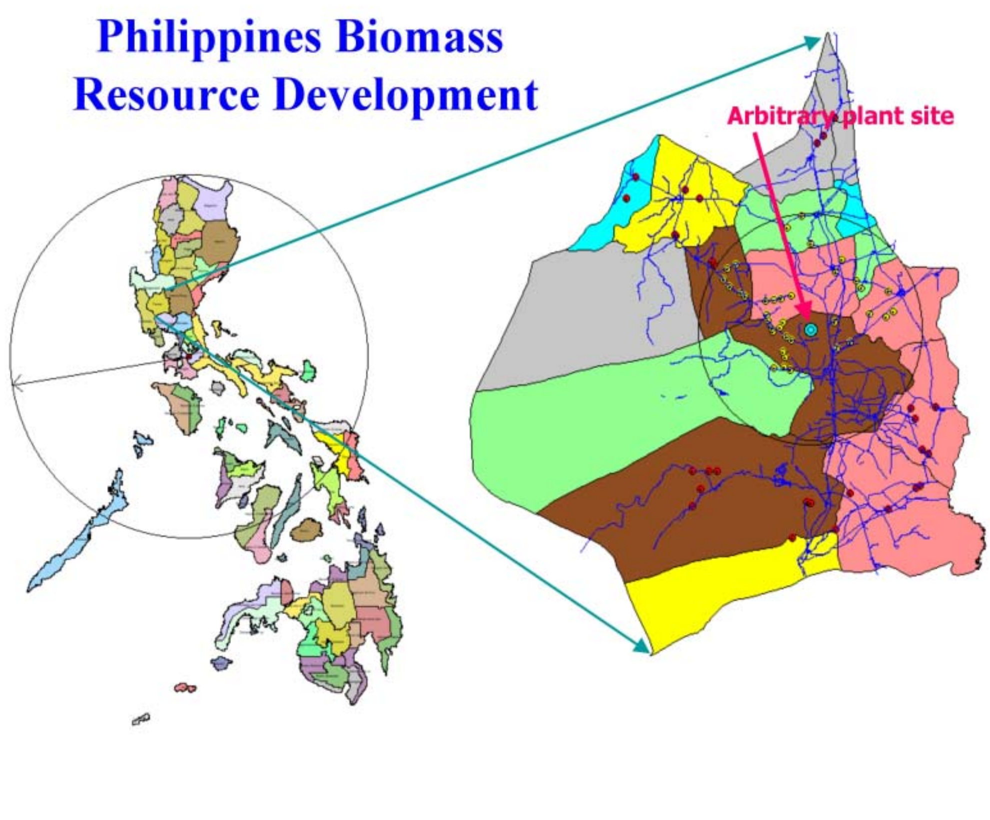
- Snapshot - usually local and involves sampling of current use such as firewood surveys
- Continuous survey and data base - normally works from Agriculture and Forestry annual data series –but only provides potential by using crop residue factors unless survey is altered
- Integrated Data Base - GIS and field-based to incorporate data from both smapshot and continuous surveys and data bases with Global Positioning systems (GPS) geolocators for key areas
- AgroEcological Zones is a GIS crop forecast and incorporates soil, insulation and rainfall, along with crop data.

In Southeast Asia, biomass is an important source of energy since fuel wood is a dominant source of energy in many parts of the region. By country, the share of biomass in the primary energy supply in 1999 was: Myanmar - 86 percent; Lao PDR - 86 percent; Cambodia - 83 percent; Vietnam - 48 percent; Indonesia - 29 percent; Philippines - 21 percent; Thailand - 17 percent; and Malaysia - 8 percent (FAO-RWEDP, 2000). Biomass energy is largely used in the household sector, and in small-scale industries.

Biomass resources, such as wood and agricultural residues, are abundant in ASEAN countries and have strong potential as fuels for green power generation. The amount of residues produced from bagasse, rice hulls, palm oil waste and wood waste in five ASEAN countries, namely: Indonesia, Malaysia, Philippines, Thailand, and Vietnam, is about 108 million tons. Of this total, bagasse accounted for 32 percent, palm oil waste 27, rice hulls 23 percent, and wood waste 18 percent (EC-ASEAN Cogen 2003/UN-ESCAP, 2000).

In 2000, the total installed ASEAN capacity of renewable energy for electricity generation, both captive and on-grid, was 20,942.46 MW. Biomass power accounted for about 8.94 percent, geothermal 11.15 percent, large hydro 77.31 percent, mini/micro hydro 2.41 percent, and solar PV and wind 0.19 percent (ACE, 2003). (Balce et al, http://www.asem-greenippnetwork.net/dsp_page.cfm?view=page&select=148)

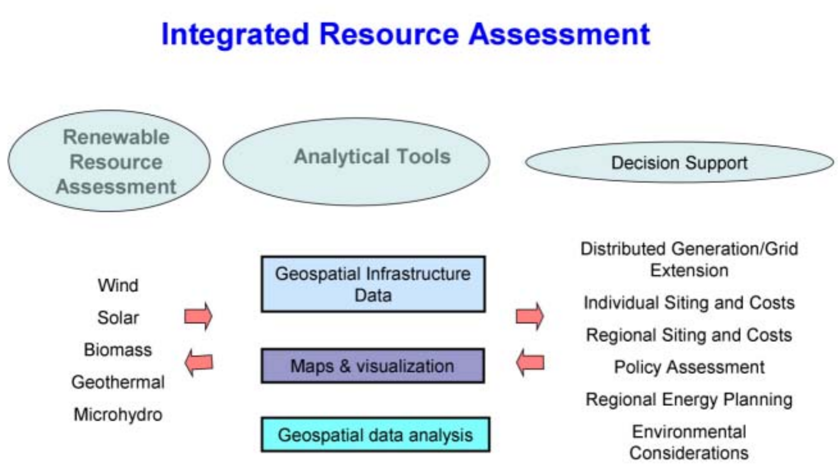
A recent biomass resource analysis for the Philippines provides another illustration of the power of resource assessment in decision-making. In this example, GIS is used to assess economic resource potential in detail. The dots are poultry establishments in the province of Tarlac. An "arbitrarily" located waste processing biomass plant, located at the blue dot, could have an economic capture radius, as illustrated, including all of the poultry farms indicated by yellow dots. The red dot farms would be outside the radius.



Making Effective Use of the Resources – GIS Integration and Opportunity Identification

A Geographic Information System (GIS) is the combination of hardware, software, data, and expertise used to create, modify, evaluate and analyze spatial or geographically-referenced information in digital format. GIS data are comprised of two components: spatial features that can be represented on a map; and attributes that provide associated information describing the features. The combination of these computerized maps and databases, as well as GIS expertise, allows for innovative analysis that cannot be achieved with other types of systems or methodologies.

The integration of the renewable energy resource data with other key geographic datasets within the GIS framework provides a comprehensive analytical platform to evaluate renewable energy development opportunities. The integrated resource assessment process incorporates the resource data with additional geographic datasets: examples include road location and condition; load centers; transmission lines; specific land use; designated protected areas; and population and settlement information. These analytical tools can be adapted to the region of interest, transforming them into powerful decision-support tools. These tools can be used to identify the infrastructure required to access the renewable energy resource in order to meet specific loads, such as remote solar home systems, off-grid hybrid village power systems, and grid-connected wind farms, and to determine the optimal sites for renewable energy systems and renewable hydrogen developments (http://www.nrel.gov/renewable_resources/) This overall assessment process is summarized below.



Stirring the Ingredients for Joining a Renewable Hydrogen Economy: Possible Pathways Forward in Asia

Charge to the Workshop

Throughout the workshop, and particularly during day three, participants will be discussing key ingredients of renewable hydrogen development in their countries and exploring next steps. The following set of questions is intended to facilitate these discussions.

The workshop discussions on key ingredients and next steps, along with country responses to this questionnaire provided below, will be synthesized into a document to assist with future renewable hydrogen planning in the region.

Renewable Hydrogen Futures: Status and Next Steps*

Country Contact Name/Email	Renewable Resources Availability					Uses	Policies	Projects	Research	Connect	Energy Sources	Political Climate	Next Steps
	Solar	Wind	Hydro	Geo	Bio								
N. Asia													
China													
Japan													
Korea													
S. Asia													
Bhutan													
India													
Nepal													
Pakistan													
Sri Lanka													
SE Asia													
Indonesia													
Malaysia													
Philippines													
Singagore													
Thailand													
European													
European Commission													
Iceland													
Netherlands													
N. and S. America													
Canada													
U.S.													

***Please provide contact name/email with this form and additional details requested on a separate sheet**

Description of form responses -- STATUS

Renewable Resources - Availability of Each Resource (note references to maps where appropriate)
0-Have not yet been assessed
1-Available
2-Preliminary Assessment
3-Detailed Assessment, part of the country
4-Detailed Assessment, all of the country

Renewable Resource - Use (note which resource and how being used)
0-Resource not yet being used
1-Resrouce being used alone, small scale
2-Resource being used alone, large scale
3-Resource being used with other resources, small scale
4-Resources being used with other resources, large scale

Renewable Policies (note what policies)
0-No policies pertaining to renewables yet
1-Non renewable energy dominate part of energy policy and economic incentrive policies
2-Roadmaps or other national strategies for renewables in place
3-Subsidies or other policies aimed at promoting renewables in place
4-Countrywide policies backing complete transition to renewables

Renewable Hydrogen Projects (note what projects)
0-No projects being planned yet
1-Projects being planned
2-Small demonstartion projects underway
3-Large demonstration projects underway or soon to be

Research (Note % of budget directed toward research and note projects)
0-No research budget for renewable energy and hydrogen yet
1-Small amount of national energy research budget directed toward renewable energy and hydrogen
2-Large amount of national energy research budget directed toward renewable energy and hydrogen

Connect--Regional and International Cooperation (note collaborators)
0-No cooperation yet with repsect to renewable energy and hydrogen
1-Country working with a few groups within country
2-Country working with multiple groups within
3-Country working with international groups and other countries

Energy (I.e., electricity) Source (note which fuel and what % for each fuel)
0-Renewable energy has no part yet
1-Non renewable fuels dominant but renewables are being explored
2-Renewables are being usedand are competitve with non-renewables

Political Climate -- Political and Economic Environment for Renewable Hydrogen (note particular factors)
0-No real support due to high costs and/or lack of political will
1-Support low due to high costs and/or lack of political will
2-Support growing as costs and/or lack of political will are declining
3-Support high as renewable electiricity costs is decreasing and/or political will is increasing

NEXT STEPS -- Please note all steps that apply

What needs to happen to move the country forward on a renewable hydrogen future
1-Assessment of renewable resources
2-Assessment of energy needs and how best to use the renewable resources
3-Assessment of how best to extract the resource for the application
4-Assessment of economic and policitcal environments for developing and deploying the resources
5-Need for changing policies that favor non renewables
6-Need for developing positive policies for renewables
7-Need for developing clear roadmaps for moving forward technically, economically and politically
8-Need for public and policy maker outreach on renewable hydrogen
9-Desire to explore how working together with other countries could help
10-Deisre to explore how working together with other international agencies could help
11-Other steps (list other steps that are appropriate but are not already listed)

Summary – Towards a Secure and Renewable Hydrogen Future for Asia

The ingredients for joining a renewable hydrogen economy include, first and foremost, the availability of renewable resources. Resource assessment quantifies information on resources, and helps accelerate development and deployment of technologies. Asia has a wealth of renewable energy resources, and many areas have more than one excellent resource. This means that Asia has a very promising renewable hydrogen future. Excellent renewable energy resources are very important assets since Asia has the highest projected energy demand, and among the lowest supply of fossil fuel reserves in the world.

Geothermal resources are particularly accessible in the Himalayan Geothermal Belt , Japan, Eastern China, the Philippines, Indonesia, and New Zealand. Hydropower resources are particularly high in several countries of mainland Southeast Asia (Thailand, Cambodia, Laos, Myanmar, and Vietnam) and the countries of insular Southeast Asia—Indonesia, Malaysia and Philippines), as well as in India, Nepal and Bhutan. Biomass potential is particularly high in many parts of the Asian regions where many biomass resources are readily available for multiple purposes.

Solar and wind resources are ubiquitous throughout the world. Areas with some of the highest solar resources are located in Asian countries. More detailed resource assessment identifies areas with particularly viable resources, as a function of season of the year and other factors that determine the usability of the resources. For both resources, access to infrastructure, such as road and transmission lines, influences the level of resource that is easiest to capture and the use that is more economical.

The integration of the renewable energy resource data with other key geographic datasets, within a GIS framework provides a comprehensive analytical platform to evaluate renewable energy development opportunities. The integrated resource assessment process incorporates the resource data with additional geographic datasets. These datasets include road location and condition, load centers, transmission lines, specific land use, designated protected areas, and population and settlement information.

Throughout the workshop, and particularly during day three, participants will be discussing key ingredients of renewable hydrogen development in their countries and exploring next steps. The best next steps will partially depend on the extent to which resources and other important factors are already known; and policies and plans are already in place for developing them, with the intent to move forward towards a renewable hydrogen economy.

The results of these discussions will be synthesized into post-workshop documents to help facilitate progress towards a renewable hydrogen future in individual locations, countries, and sub-regions throughout the Asia / Pacific region.

References

The following is a compilation of the references provided throughout the document. These sources, mainly given as web sites, are listed in the order they appeared in each of the three major sections of the document. These references give a selection of resources for the materials provided in the document.

Renewable Hydrogen Fundamentals

Global solar resources:
http://www.oksolar.com/technical/daiy_solar_radiation.html

Conversion of Renewable Energy into Useful Energy
Mann, Renewable Hydrogen Forum Report, http://ases.org/

Energy Currencies
Prof. D. S. Scott on “hydricity,”. International Journal of Hydrogen Energy, 29 (April 2004), 449-452

Resource Intermittency and Energy Storage
Scott, Renewable Hydrogen Forum Report, http://ases.org/

International Energy Agency
http://www.iea.org/

Case Study Demonstration Projects
U.S. Department of Energy
http://www.eere.energy.gov/hydrogenandfuelcells/hydrogen/iea/case_studies.html

International Partnership for the Hydrogen Economy
General Information http://www.iphe.net/
Country Links http://www.iphe.net/ipheinternationallinks.htm
Country Roadmaps http://www.iphe.net/ipheroadmaps.htm

U.S. National Hydrogen Energy Roadmap,
www.eere.energy.gov/hydrogenandfuelcells/pdfs/national_h2_roadmap.pdf

European Commission Report of Hydrogen Energy and Fuel Cells
www.europa.eu.int/comm/research/energy/pdf/hydrogen_summary_report.pdf

Production -- Electrolysers
Proton Energy Systems http://www.protonenergy.com/

Comparisons of Production Options
Goswami, D.Y., Mirabel, S.T., Goel, N., and Ingley, H.A., "A Review of Hydrogen Production Technologies" Proceedings of the First International Conference on Fuel Cell Science, Engineering and Technology, Rochester, New York, April 21-23, 2003

Comparison of Production Options
Bull, Renewable Hydrogen Forum Report, http://ases.org/

Storage and Transport
Amos, W.A. (1998) Costs of Storage and Transporting Hydrogen, NREL/TP-579-25108. National Renewable Energy Laboratory, Golden, CO.

Comparison of Options
NREL/TP-570-27079, 1999
Kartha, Renewable Hydrogen Forum Report, http://ases.org/

Energy, Emissions, and Impacts
www.hydrogenhighway.ca.gov/facts/einwelltowheel.pdf
Friedman, Renewable Hydrogen Forum Report, http://ases.org/

Codes and Standards
http://www.fuelcellstandards.com/,
Partnership for Advancing the Transition to Hydrogen (PATH) www.hpath.org/TechnicalReport.pdf

Education and Outreach
IPHE examples http://www.iphe.net/ipheinternationallinks.htm
Hydrogen.com http://www.hydrogen.com/
NREL http://www.nrel.gov/

Economics
H. Scheer, The Solar Economy Earthscan, London, 2002
Mann, Renewable Hydrogen Forum, http://ases.org/)

Water
Western Resource Advocates, The Last Straw, http://www.westernresources.org/energy/
Scott, and Mann, Renewable Hydrogen Forum, http://ases.org/)

Environmental
Coal-fired power plants and health htt;?//www.abtasspc/cp
Urban air quality and human health http://yosemite.epa.gov

Renewable Energy Policy Levers
IEA report (http://www.iea.org/dbtw-wpd/bookshop/add.aspx?id=177),
Policy examples NREL – Renewable Energy Compendium SARI-E Phase II / Sri Lanka, 2004 Draft

International Experience

IPHE Country Information
http://www.iphe.net/

Iceland
Further reading can be found in a chapter by T.I. Sigfusson in the forthcoming book:
Mitigation and Adaption Strategies for Global Change, Ed. Robert Dixon , KLUWER Publishing 2004.

Germany
http://www.eihp.org

European Commission
www.hynet.info/ecactiv/docs/highlg/hydrogen-report_en.pdf,

Southeast Asia
http://www.aseansec.org/home.html

Thailand
http://www.netmeter.org/en/energy_sources
.http://www.eia.doe.gov/emeu/cabs/indonesa.html

Malaysia
http://www.fuelcelltoday.com/FuelCellToday/IndustryInformation/IndustryInformationExternal/NewsDisplayArticle/0%2C1602%2C4530%2C00.html

Singapore
http://www.iea.org/dbtw-wpd/textbase/pamsdb/jrcountry.aspx?country=Singapore

Philippines
http://www.doe.gov.ph/servlet/page?_pageid=2778&_dad=portal30&_schema=PORTAL30)

Possible Paths Forward

International Energy Outlook 2003
www.eia.doe.gov/oiaf/ieo/index.html.

NREL Resource Assessment
http://rredc.nrel.gov/

Geothermal
http://www.worldenergy.org/wec-geis/publications/reports/ser/geo/geo.asp

Hydropower
http://www.worldenergy.org/wec-geis/publications/reports/ser/hydro/hydro.asp
http://www.asem-greenippnetwork.net/dsp_page.cfm?view=page&select=132
http://www.doe.gov.ph/servlet/page?_pageid=1062,1064,1066&_dad=portal30&_schema=PORTAL30

Wind
www.nrel.gov/docs/legosti/fy97/22223.pdf
http://www.nrel.gov/wind/wind_pubs.html
http://www.rsvp.nrel.gov/wind_resources.html

Solar
http://rredc.nrel.gov/solar/#archived

Biomass
http://toms.gsfc.nasa.gov/aerosols/aerosols_v8.html
http://www.asem-greenippnetwork.net/dsp_page.cfm?view=page&select=148)

GIS Integrated Analysis
http://www.nrel.gov/renewable_resources/

Advances in renewable energy, hydrogen fuel and fuel cell technologies along with changes in markets and policy are the driving forces that will shape the future of energy - a future that is likely to be more: